NASA Technical Memorandum 208545

Research and Technology 1998 Annual Report

John F. Kennedy Space Center

About the Cover

The three technology links to access space are the Launch and Launch Vehicle Processing Systems, the Payload and Payload Carrier Processing Systems, and the Landing and Recovery Systems. These technology links support KSC's Strategic Roadmap to the Future. The center illustration depicts KSC as the future Spaceport Technology Center.

Cover art: by Caroline Zaffery
Dynacs Engineering Co., Inc.
Engineering Development Contract

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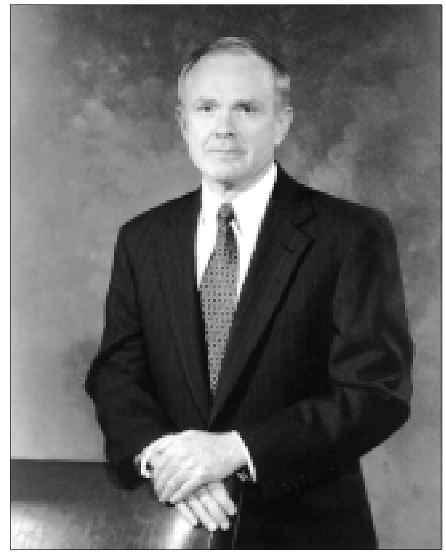
Foreword



As the NASA Center responsible for preparing and launching space missions, the John F. Kennedy Space Center (KSC) is placing increasing emphasis on its advanced technology development program. KSC is transitioning from an operations to a spaceport technology development center. Our technology development encompasses the efforts of the entire KSC team, consisting of Government and contractor personnel, working in partnership with academic institutions and commercial industry. This edition of the KSC Research and Technology 1998 Annual Report covers the efforts of these contributors to the KSC advanced technology development program, as well as our technology transfer activities.

Gale Allen, Associate Director of KSC's Technology Programs and Commercialization organization, (407) 867-6226, is responsible for publication of this report and should be contacted for any desired information regarding the advanced technology program.

Roy D. Bridges, Jr.
Director

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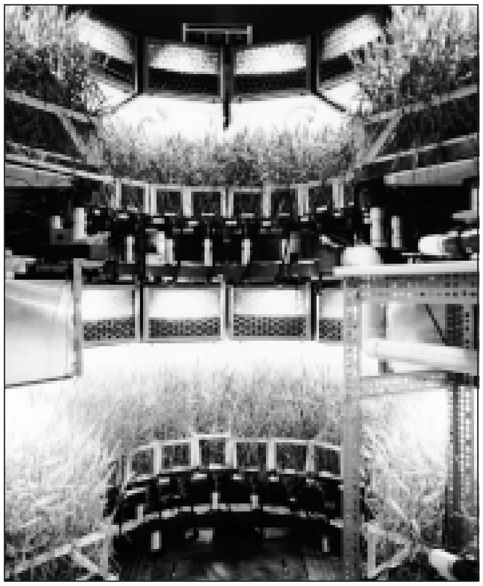
Technology Programs and Commercialization

Introduction

John F. Kennedy Space Center (KSC) maintains a vigorous applied development program in support of its designation as the NASA Center of Excellence for Launch and Payload Processing. In accordance with this mission, KSC is establishing its Spaceport Technology Center (STC) that supports the development and utilization of technologies required to access space. The STC is composed of three pillars, Launch and Launch Vehicle Processing Systems, Payload and Payload Carrier Processing Systems, and Landing and Recovery Systems. The STC forms the foundation for KSC's growth into its future role as a development center for support of the Nation's increasingly commercial space initiatives. Having focused historically on applied development programs supporting industrial-level operations and processes, KSC technology and expertise are uniquely suited to support the development of commercial products and services. Both rapid-turnaround problemsolving and design techniques and long-term investment in critical operations technology form the core of KSC's research and development programs.

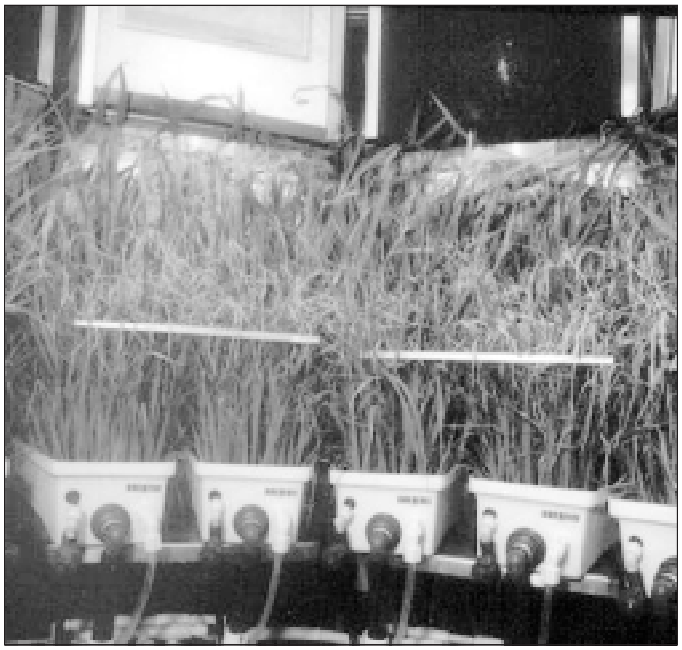
KSC aggressively seeks industry participation in its research initiatives and proactively seeks to transfer its innovative expertise and technology to commercial space initiatives and the nonaerospace commercial sector. Programs and commercialization opportunities available to American industry and other institutional organizations are described in the Technology Programs and Commercialization Office Internet Web site at *http://technology.nasa.gov*.



Life Sciences

The Life Sciences research and technology program at the John F. Kennedy Space Center (KSC) primarily supports the development of advanced technologies for application in life support for long-term human habitation in space. The near-term focus of the Advanced Life Support (ALS) project is biomass production improvement, resource recovery development, and system engineering. Plant Gravitational Biology is investigating lighting and nutrient-delivery hardware systems, the effects of environmental conditions (i.e., carbon dioxide and temperature) on plants growing in flight-type chambers, and microgravity effects on plant growth and development. These efforts are directed toward evaluating and integrating components of bioregenerative life support systems and investigating the effects of a space environment on photosynthesis and carbon metabolism in higher plants.

Candidate Crop Evaluation for Advanced Life Support and Gravitational Biology and Ecology



Rice cv. Ai Nan Tsio (grown in the BPC to determine the effect of atmospheric contaminants on productivity and suitability for advanced life support applications)

The primary objective of this task is to define environmental conditions and horticultural methodologies to optimize edible biomass production in candidate crop species. This task includes coordination of NASA-supported tasks at the New Jersey NASA Specialized Center of Research and Training (NJNSCORT) for tomato and salad crops, at the Tuskegee Institute for peanut and sweet potato, at Utah State University for wheat and soybean, and at NASA Research Announcement (NRA) grant recipients for other candidate crops. This task involves the screening of different cultivars and the compilation of all crop growth data for inclusion in a crop handbook. This effort will use a standardized testing procedure for all candidate crop species that were selected from the Crop Selection Meeting held at KSC in May 1997. This task will develop crop management strategies for reuse of nutrient solutions with a special emphasis on biologically active organic materials that may accumulate in the nutrient solution.

The development of a bioregenerative life support system requires that the horticultural methodologies and the range of suitable environmental conditions for various candidate crops be well understood. This is an integrated activity requiring coordination with several research organizations and ongoing Advanced Life Support (ALS) tasks in order to maximize the benefit to the ALS program.

The candidate crop research and technology development conducted at KSC during 1998 included:

- Rice: A large-scale test of rice, cultivar Ai Nan Tsio, obtained from Utah State University, was evaluated in the Biomass Production Chamber (BPC) under filtered and unfiltered atmospheres (see the figure).

- Dry Bean: Tests to determine the suitability of a dry bean (Etna) and snap bean (Hystyle) for hydroponic production under elevated carbon dioxide conditions were initiated in collaboration with Cornell University.

- Radish: Tests to determine the effect of narrow-band spectral radiation delivered through light-emitting diodes (LED's) were initiated in collaboration with the ALS lighting task.

- Chard: Tests were conducted in collaboration with the nutrient delivery task to compare the results of the nutrient film technique to solid substrates, including various zeolite formulations.

- Table Beet: Tests were conducted in collaboration with the National Research Council (NRC) on the ability of table beet to accumulate sodium (Na) in the leaf tissue.

- Spinach: Tests to determine the effect of narrow-band spectral radiation delivered through LED's were initiated in collaboration with the ALS lighting task.

- Sweetpotato: A comparison of the nutrient management system developed at KSC was compared with that of Tuskegee Institute.

- White Potato: Tests were conducted in collaboration with the ALS lighting task to determine the maximum amount of light that can be perceived by potatoes during the dark cycle without inhibiting tuber formation.

- Wheat: Tests were conducted in collaboration with the resource recovery-water recovery task to determine the effect of gray water additions to the nutrient solution on growth and development of wheat.

- Lettuce: Tests were conducted in collaboration with the resource recovery-water recovery task, to determine the effect of gray water additions to the nutrient solution on growth and development of lettuce.

Key accomplishments:

- 1997: ALS program Crop Selection Meeting hosted by KSC in May. Candidate crop testing in the BPC test bed of the Breadboard Project was completed in December.
- 1998: Nine peer-reviewed articles were either published or accepted for publication.

Key milestones:

- 1999: First edition of the handbook for ALS candidate crops.
- 2000: 100-percent improvement in productivity of soybean and peanut.

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Participating Organizations: Dynamac Corporation (Dr. G.W. Stutte), Utah State University (Dr. B. Baugbee), Cornell University (D. DeVillers), NRC (Dr. G. Subbarao), and Tuskegee University

Plant Nutrient Delivery Systems

During long-term space missions, a reliable nutrient delivery system (NDS) is required to cultivate plants that yield a satisfactory quantity of edible biomass. Many plant nutrient delivery systems used on Earth will not function effectively in space. An effective plant nutrient delivery system for spaceflight must provide adequate amounts and uniform distribution of water, nutrient, and oxygen in the root zone, while at the same time, prevent release of free nutrient solution to the atmosphere. The ultimate goal is to design a nutrient delivery system that is capable of sustaining plants for long periods under spaceflight conditions yet requires minimal system maintenance and limited demands on crew time. For extended plant cultivation in space, root-zone media will require more than just an initial loading of water and nutrients due to losses from plant evapotranspiration and nutrient uptake. Recent plant testing for spaceflight has begun to explore active nutrient delivery concepts in which water and nutrients are replenished on a continuous basis for long-term plant growth. At KSC, a series of ground-based tests are being conducted on various recirculating nutrient delivery systems that are proposed for extended space expeditions. The merits of each nutrient delivery system are largely based upon the performance of different shoot and root-zone crops in terms of edible biomass yield from complete growth cycles. To date for several crop species, these nutrient delivery systems were characterized with respect to plant water use, ion uptake, and nutrient solution pH changes over time.

Key accomplishments:

- Developed and tested recirculating nutrient delivery systems that accommodate a range of shoot and root-zone crops.
- Explored nutrient buffered concepts to simplify system management, particularly for spaceflight.
- Developed a protocol for continuous salad crop production for the Lunar-Mars Life Support Test Project Phase III at Johnson Space Center and conducted comparative studies with salad crops with zeoponic media, porous tubes, and nutrient thin-film hydroponic nutrient delivery systems.

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Participating Organization: Dynamac Corporation (Dr. G.D. Goins)

ASTROCULTURE™ (Subirrigated Porous Tube System) Root Tray With Lettuce Plants at 8, 15, and 22 Days After Seeding in ARABASKETS Filled With Zeoponic Growing Media

Plant Lighting Systems

Mature USU-SuperDwarf Wheat Plants Growing Under an Array of 600-Nanometer Red Aluminum-Gallium-Arsenide (GaAlAs) LED's

A major challenge to growing plants in space will be controlling and supplying sufficient quantity and quality of light. The primary objective of this task is to significantly improve the efficiency of converting electrical energy into edible plant biomass. Technology development efforts are focusing on obtaining light sources to increase electrical conversion efficiency of lighting systems and methods of collecting, transporting, and distribution of photosynthetically active radiation (PAR) to the crop canopy. Current research includes investigations of light sources and methods that deliver PAR to crop plants that will produce food for the space inhabitants. Two new sources that show great promise in delivering PAR to the plant canopy include microwave lamps and light-emitting diodes (LED's). Microwave lamps are a new technology that use microwave energy to energize an electrode-less sulfur-filled element. It has a spectral output similar to other high-intensity discharge sources but uses 20 to 30 percent less energy for comparable output. LED's are a promising electric light source for space-based plant growth chambers and bioregenerative advanced life support because of their small mass and volume, solid state construction, safety, and longevity.

Key accomplishments:

- Completed LED experiments with different food crops to investigate carbon exchange and stomatal conductance differences between light treatments and species.
- Determined low-level irradiance requirements during the dark period for photoperiodic-induced tuberization of potato.
- Evaluated solid-state magnetron microwave lamp systems.

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Participating Organization: Dynamac Corporation (Dr. G.D. Goins, N.C. Yorio, and G. Koerner)

Microbial Ecology of Bioregenerative Life Support Systems for Space Exploration

The stability of microbial communities within closed bioregenerative systems is an important component of overall system stability due to the risk of human or plant disease and the reliance on microbially based reactors for waste processing. Effective management of microbial communities requires an improved understanding of the complex interactions among microorganisms within Advanced Life Support (ALS) systems that, in turn, depend on advancements in rapid and reliable monitoring techniques. The purposes of this work are to develop monitoring tools that allow for a better understanding of the microbial risks associated with bioregenerative life support systems and to evaluate the suitability of these tools for use in Moon or Mars bases. Experiments with prototype ALS subsystems under development at KSC (e.g., plant production systems and bioreactors) will assess the ability of different techniques to identify changes in the overall stability of microbial communities and detect the presence of specific human or plant pathogens before the health of the system is adversely affected. These efforts will help identify the best approaches for managing microbial risks within the systems in addition to evaluating specific sensor technology.

The primary effort this year involved the development of advanced analytical software for a rapid, simple monitoring method based on functional profiling of microbial communities. This approach, which was developed by the Dynamac staff, detects respiration of 95 separate carbon sources using a redox sensitive dye. Initial testing indicated that the community-level physiological profiles (CLPP's) can detect small changes in microbial communities associated with prototype ALS systems. The new software enables automated analysis of the kinetic profile of dye reduction for each of the 95 separate carbon sources based on nonlinear regression. The parameters of the nonlinear curve (lag, maximum rate, asymptote, and integral) can be automatically exported into the statistical software for subsequent multivariate analysis.

Another major effort this year involved assessment of the effects of bacterial diversity (the number and relative abundance of bacterial types) in prototype ALS systems on the survival of introduced opportunistic human pathogens. Ecological theory suggests that greater diversity may decrease the likelihood of potentially deleterious organisms, such as opportunistic human pathogens, from growing in microbial habitats within ALS systems. In collaboration with scientists from the University of South Florida, the University of Virginia, and Michigan State University, the relative survival of opportunistic human pathogens in systems with different levels of diversity was evaluated. Such studies will be important in defining effective approaches for inoculating bioregenerative life support systems.

A third focal area involved the development of molecular tools for assessing microbial communities in bioregenerative ALS. Several profiling techniques based on the detection of genetic variation within bacterial communities were used to characterize ALS systems, including Terminal Restriction Fragment Length Polymorphisms (T-RFLP's), Randomly Amplified Polymorphic DNA (RAPD), and Amplified Fragment Length Polymorphism (AFLP). All of these methods involve amplification of genes using the polymerase chain reaction (PCR). T-RFLP analyses were performed at Rutgers University while the other approaches were performed at KSC in collaboration with the University of Virginia.

Key accomplishments (1998):

- Submitted a new technology report for the CLPP technique.
- Developed the CLPP analysis software.
- Completed the report comparing the effectiveness of the different analytical approaches on classifying microbial communities from plant production systems and bioreactors.
- Completed studies evaluating the effect of community diversity on the survival of human pathogens in plant production systems and bioreactors.
- Completed the analysis and preliminary report on T-RFLP analysis of samples from ALS biomass production systems.
- Established molecular microbial ecology facilities at KSC and completed the preliminary analysis of ALS samples using RAPD and AFLP.

Key milestones (1999):

- Complete the testing of the CLPP software, including the publication of the results and the distribution of the product to interested research organizations.
- Expand the molecular microbial ecology infrastructure at KSC, including the purchase of a DNA sequencer.

- Develop and test miniaturized biosensors based on bioluminescent bioreporter integrated circuit (BBIC) technology in collaboration with the University of Tennessee.
- Complete the initial assessment of the effects of diversity on the microbial risks associated with the growth of opportunistic human pathogens.

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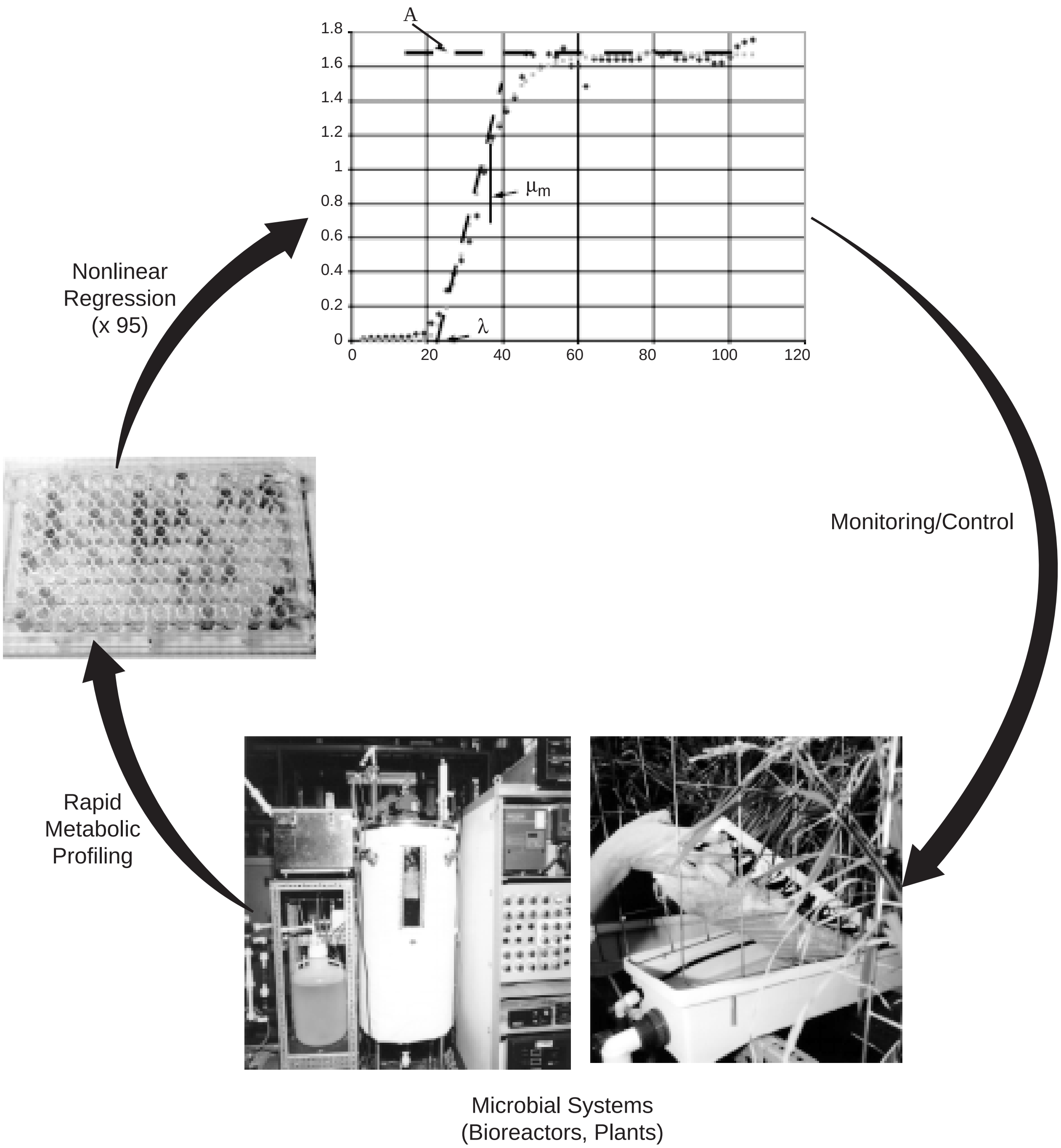
Participating Organizations: Rutgers University (Dr. L. Kerkhof), University of Virginia (Dr. A. Mills), University of Tennessee (Dr. G. Saylor), University of South Florida, Michigan State University, and Dynamac Corporation (Dr. J. Garland)



Microbial Monitoring for the ALS

Mechanical Engineering

The Mechanical Engineering program at the John F. Kennedy Space Center (KSC) supports the development of technology with analysis, design, and operation of launch and ground support equipment for space flight vehicles. Technology is advanced by a broad variety of analysis including structural deflection, dynamic response, stress, dynamic data requirements, reduction, and processing. Also included are single and multiphase flow, cryogenic fluid flow and storage, thermal insulation development, and fracture mechanics. Launch-induced environments are predicted and evaluated with test spectra, modal testing, portable dynamic data acquisition, and analysis. Mechanical Engineering also covers system and mechanism troubleshooting, component testing, and development of tools, devices, and systems for fabricating systems and obtaining required cleanliness.

Insulation Testing Using a Cryostat Apparatus With Sleeve

The method and equipment of testing continuously rolled insulation materials was developed at the KSC Cryogenics Test Laboratory in 1998. The testing of blanket and molded products is facilitated by the technology. Materials are installed around a cylindrical copper sleeve using a wrapping machine. Large size insulation test articles that are 6.69 inches inside diameter by 36 inches long by up to 2 inches in thickness can be fabricated and tested. The sleeve is slid onto the vertical cold mass of the cryostat. The gap between the cold mass and the sleeve measures 0.035 inch. The cryostat apparatus (see figure 1) is a liquid nitrogen boiloff calorimeter system that enables direct measurement of the apparent thermal conductivity (k-value) of the insulation system at any vacuum level between $5x10^{-5}$ and 760 torr.

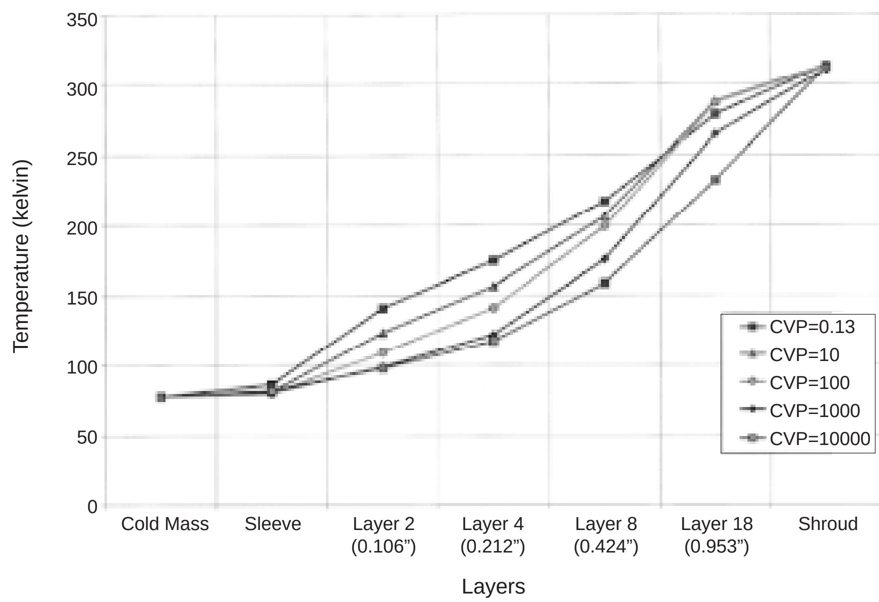


Figure 2. Layer Temperature Profiles for Different Vacuum Levels (Cryostat 1, Test Series C114)

Figure 1. Cryostat Apparatus — Liquid Nitrogen Boiloff Colorimeter System

Sensors are placed between layers of the insulation to provide complete temperature-thickness profiles. The temperatures of the cold mass [maintained at 77.8 kelvin (K)], the sleeve [cold boundary temperature (CBT)], the insulation outer surface [warm boundary temperature (WBT)], and the vacuum chamber (maintained at 315 K by the thermal shroud) are measured. Layer temperature profiles as a function of the vacuum level, as shown in figure 2, indicate the three ranges (radiation, gas conduction, and convection) of dominant heat transfer modes. Heat leak through to the ends of the cryostat is reduced to a negligible amount by the use of liquid nitrogen filled chambers on the top and bottom. The cryostat apparatus is supplied with liquid nitrogen subcooled to approximately 77.8 K. The upper guard chamber is kept at a slightly higher pressure (0.150 ±0.050 pound per square inch differential) than the test chamber to preclude the condensation of any boiloff gas as it is exiting through the center of the guard. During the boiloff replenish phase, the guard chambers must be maintained at 0.6 ±0.1 pound per square inch gage for minimum heat leak. Steady-state boiloff conditions are achieved in 6 to 12 hours after an initial chilldown and thermal stabilization period of at least 24 hours. Typical plots of flow rate and k-value are shown in figure 3. (Note that the end of the first plateau is the point at which the replenish of the guard chambers is terminated.) The vacuum pumping system consists of a combination of turbopumps and mechanical pumps plus a finely metered gaseous nitrogen supply for controlling the pumping speed. All measurements are recorded on a National Instrument Field Point data acquisition system using LabView software.

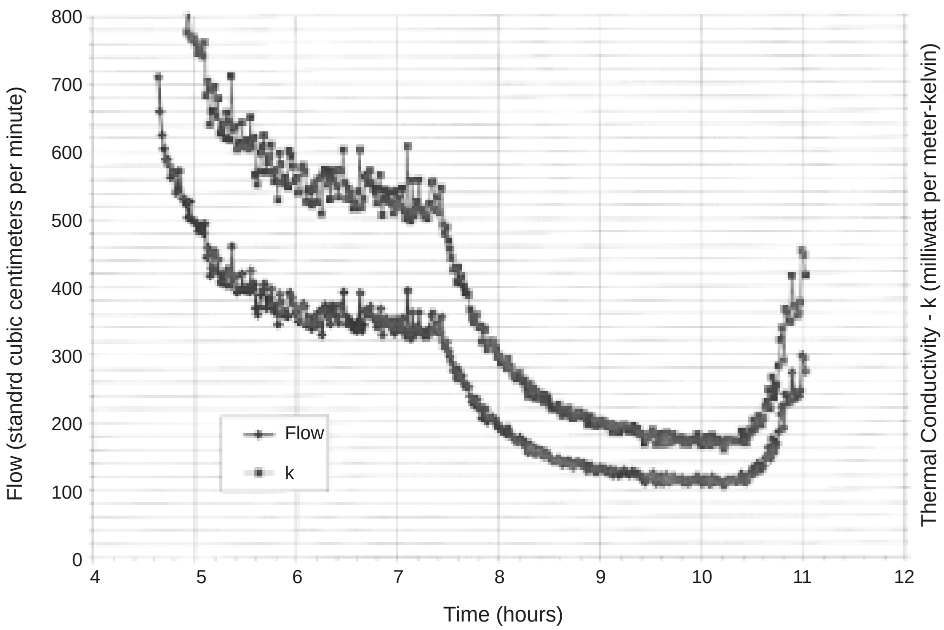


Figure 3. Liquid Nitrogen Boiloff Test Perfomance [Cryostat 1, Test Series C114, Run 10 (0.1 micron)]

For this cryostat apparatus, the measurable heat gain is from 0.2 to 20 watts (which corresponds to a boiloff flow rate of 50 to 5,000 standard cubic centimeters per minute). The surface area for a typical 1-inch-thick insulation test article is 969 square inches. The steady-state measurement of the insulation performance is made when all temperatures and the boiloff flow are stable. The k-value of the insulation is directly computed from the boiloff rate, the cold mass geometry, and the delta temperature (WBT-CBT).

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Participating Organization: Dynacs Engineering Co., Inc. (S. Augustynowicz)

Development of a Multipurpose Cryostat for Insulation Testing

A multipurpose cryostat apparatus (Cryostat-2) was designed and fabricated at the KSC Cryogenics Test Laboratory. The apparatus can be used for testing insulation materials or cryogenic couplings and seals. Using custom handling fixtures, the inner assembly is easily and quickly removable for installation on an 18-inch-wide insulation-wrapping machine. Alternatively, the lower thermal guard can be removed for the testing of flat-plate configurations. The stainless-steel inner vessel is a cylinder 5.2 inches in diameter by 10.5 inches in length. The overall dimensions of the vacuum chamber are 12 inches in diameter and 26 inches in length. The figure shows the inner assembly on its work stand adjacent to the vacuum chamber assembly. Thermal guarding of each end is provided by a 5-inch-diameter by 5-inch-long stack of aerogel composite disks with silvered film layers between each disk. A single 1/2-inch diameter by 19-inch-long fluid feed-through constructed from thin-wall bellows and a VCR coupling allow for liquid nitrogen filling, venting, and boiloff. The entire inner assembly is suspended by three Kevlar threads that are attached to the flange of the vacuum chamber. The design maximum heat leak for the system is 0.025 watt at a high vacuum level to 0.050 watt at a soft vacuum level. The surface area for a typical 1-inch-thick insulation test article is 969 square inches. The measurable heat gain is estimated to be from 0.100 to 40 watts (which corresponds to a boiloff flow rate of 25 to 9,666 standard cubic centimeters per minute). The operating temperature range is 77 to 373 kelvin while the operating pressure range is 1×10^{-6} torr to 1,000 torr. Cryostat-2 is currently being used for testing continuously rolled insulation materials.

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Cryogenics Test Laboratory

The KSC Cryogenics Test Laboratory is located at the NASA Development Testing Laboratory (Building M7-581). A variety of industry, aerospace, and research activities in the area of cryogenics and propellant systems is supported. These activities include design, fabrication, testing, analysis, field testing, and engineering evaluation. The laboratory facilities include a liquid nitrogen flow test area, a valve test cell, a high-vacuum workstation, and a liquid nitrogen boiloff calorimeter (Cryostat-1). Cryogenic insulation system development is the main line of work at this time. The areas of expertise include:

- Cryogenic insulation systems
- Cryogenic valves and devices
- Connectors, seals, and seal materials
- High vacuum and leakage
- Design concepts and prototype fabrication
- Flow testing and analysis

Plans for 1999 include:

- Activation of a multipurpose cryostat apparatus (Cryostat-2)
- Conversion to National Instruments FieldPoint data acquisition systems
- Addition of instrumentation and controls to the flow test area
- Enhancement of valve test cell

The renovation of a 5,000-square-foot facility to house test, checkout, and research activities is also being planned for completion in late 1999.

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Verification Test Article Project

During a Shuttle launch, ground support equipment and structures in the proximity of the launch pad are subjected to intense vibration due to acoustic pressure generated by rocket exhausts. Continuous monitoring of launch-critical loads (acoustics) and simultaneous structural response (vibration and strain) is vital for design of new and proactive maintenance of existing structures. By the end of 1996, the collection of acoustic, vibration, and strain data from seven launches from Launch Pad 39A was completed on a cantilever beam, called the Verification Test Article (VETA). Analyzed data from these launches was crucial for validating a random vibration response model based on the deterministic approach developed at KSC. A detailed report outlining the validation methodology was released in 1997.

VETA measurements proved extremely valuable in characterizing two separate zones of acoustic loading on the ground support equipment. Tests showed the liftoff peak acoustics (between T+2 to T+7 seconds) are often overshadowed by a significant secondary peak (between T+10 and T+17 seconds). This second peak, the "plume impingement" peak, is directly attributable to the Shuttle roll maneuver. The liftoff peak is composed primarily of high-frequency components above 50 hertz. The secondary plume impingement effect contributes significantly to the structural resonances because of its low-frequency composition. Limited launches and failed sensors restricted analysis efforts to evaluate effects of launch trajectory, multimodal contribution, and effects of higher modes on the overall response and prediction confidence intervals.

Key accomplishments:

- 1998: Several lectures on rocket noise and vibration were presented at the Universities of Perth and Adelaide in Australia. The acoustibox concept was tested on several launches and results were positive. To record launch-induced acoustics, a totally self-contained acoustibox (operates on batteries) was installed on the launch pad and has (1) the capability to "wake up" prior to launch and to store the recorded data and (2) postlaunch retrieval software.

Key milestone:

- 1999: Efforts will be aimed toward developing a totally indigenous unit for use by KSC operations, in line with NASA policy of "better, faster, cheaper."

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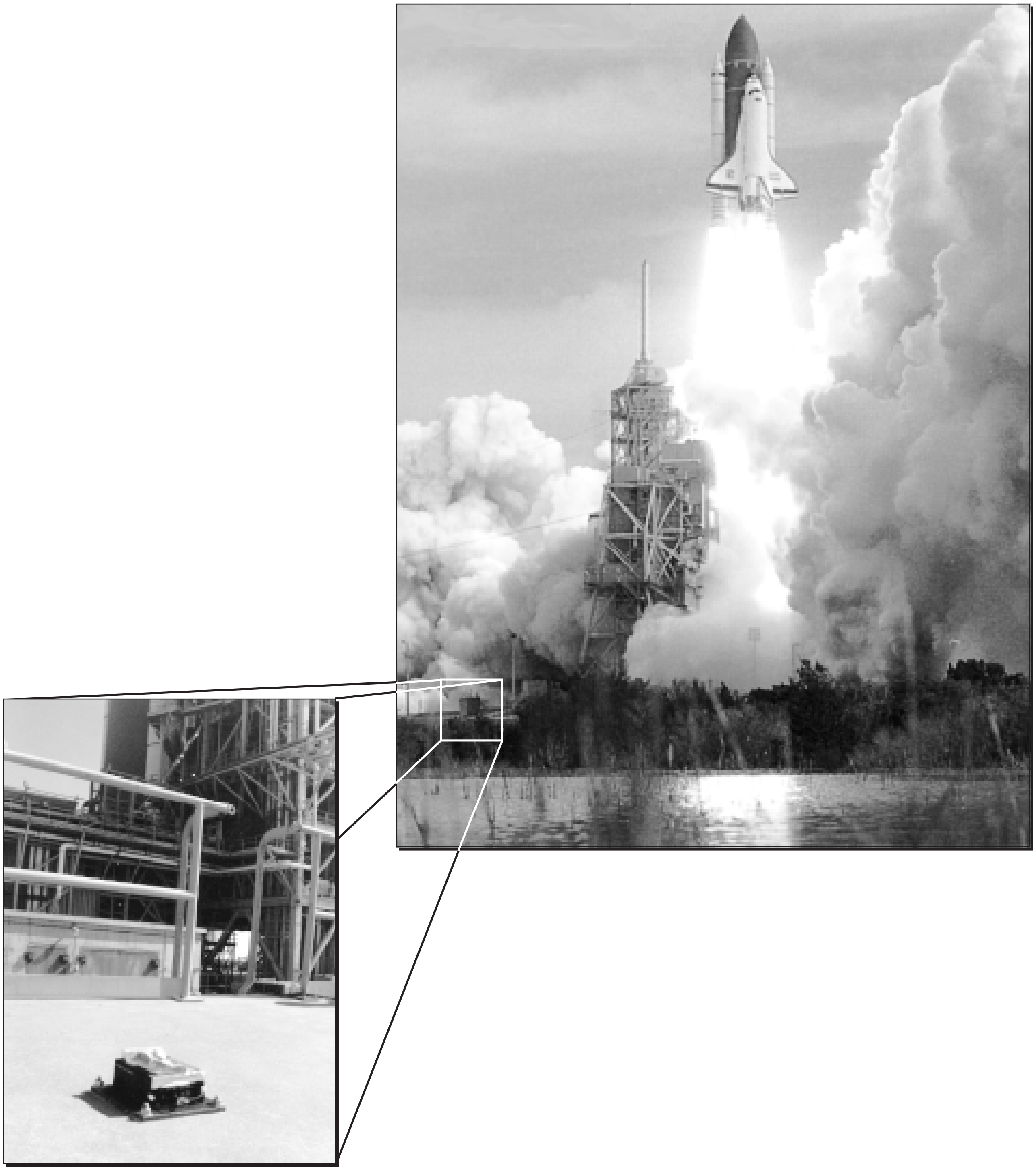
Participating Organizations: Dynacs Engineering Co., Inc. (R.N. Margasahayam), United Space Alliance (F. Walker), and Information Dynamics, Inc. (O. Varosi and L. Albright)



Self-Contained Acoustibox on the Launch Pad

Liquid Nitrogen Feed System and Subcooler for the Cryostat

A special liquid nitrogen feed system for the insulation test cryostat (Cryostat-1) was designed and constructed at the KSC Cryogenics Test Laboratory. The cryostat requires a stable supply of liquid nitrogen near the normal boiling point (77.36 kelvin at atmospheric pressure) for run times of up to 12 hours. The feed system consists of an adjustable pressure phase separator (APPS) unit, a 1/2-inch vacuum-jacketed pipeline with cryo-vent devices, and a subcooler unit. The APPS unit maintains a supply of liquid nitrogen saturated at 19 ±1 pound per square inch gage and allows insulation testing to be performed independent of other tests using the main supply dewar. The subcooler unit provides 11 ±0.5 pound per square inch gage liquid nitrogen conditioned at approximately 77.8 kelvin to the cryostat inlet manifold. The liquid reservoir of the subcooler consists of a stainless-steel vessel 10.75 inches in diameter by 24 inches tall that is enclosed by an outer shell. The annular space is filled with excess liquid from the inner vessel and vented to the atmosphere. The levels in the liquid reservoir and outer shell are maintained by an adjustment of a control valve from the main supply line. Tube fittings on the top allow for simple installation or removal. The exposed fittings are quenched in the liquid nitrogen overflow from the outer shell to eliminate a heat leak. An overall view of the subcooler unit is shown in the figure.

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Liquid Nitrogen Flow Test Area

The liquid nitrogen flow test area was activated at the KSC Cryogenics Test Laboratory. The area includes a 6,000-gallon dewar that supplies liquid to low-flow and high-flow test sections. The low-flow section, fed by an adjustable pressure phase separator and a 1/2-inch vacuum-jacketed pipeline, can provide 0 to 100 pounds per square inch gage at up to15 gallons per minute. An inline density meter built by Dynacs Engineering Co., Inc., is included to monitor flow conditions and transients during a test. The high-flow section includes run piping with 3-inch and 6-inch diameter test sections that are adaptable to any size component up to a 12-inch nominal pipe size. The high-flow section provides flow rates of up to 1,000 gallons per minute at 250 pounds per square inch gage. Instrumentation and controls are tailored to the requirements for a given test using the new National Instruments FieldPoint equipment and LabView software for the data acquisition system. An overall view of the test area is shown in the figure.

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Participating Organization: Dynacs Engineering Co., Inc. (Z. Nagy)

Analysis of Nonstationary Signals Using Wavelets for Extracting Resonances

To determine the frequency composition of a signal for mechanical analysis, signal processing tools such as the Fast Fourier Transform (FFT) and the Short Time Fourier Transform (STFT) are used. However, the use of Fourier analysis for frequency component extraction is restricted to band-limited stationary signals. Thus, small transients may not be detected due to a smoothing effect of the FFT, or the FFT spectrum may be smeared due to frequency ramping or discontinuities in the signal. Space Shuttle launch-induced acoustic and vibration signals can be classified as nonstationary random and exhibit features of a very short duration transient. Various techniques have been employed to overcome the limitations of the FFT for nonstationary data. These techniques include windowed Fourier Transform (Gabor or STFT), synchronous sampling to remove revolutions-per-minute ramp effects, Wigner-Ville analysis, and wavelet analysis.

Wavelet analysis is based on a fundamentally different approach in which the signal is decomposed on a series of special-basis functions called wavelets, which are localized in time and have an integral value of zero. Wavelet analysis can pinpoint local phenomena in nonstationary signals and provide the capability to compress or de-noise a signal without appreciable degradation, while preserving both high-frequency and low-frequency components. Wavelet techniques can be extended to detect and analyze impending bearing failure in rotating machinery (see the graphs). Planned developments will use the MATLAB platform, a commercially available software.

Key accomplishments:

- 1998: The wavelet analysis methods were applied to Space Shuttle launch-induced acoustic and vibration signals to highlight key low-frequency components affecting structural resonance. The wavelet analysis methods were applied to liquid oxygen pump rotating machinery analysis for condition monitoring, machine diagnostics, and bearing fault detection and prediction.

Key milestones:

- A comparative evaluation of the FFT and wavelets is planned. Effectiveness of different wavelet techniques will be studied.

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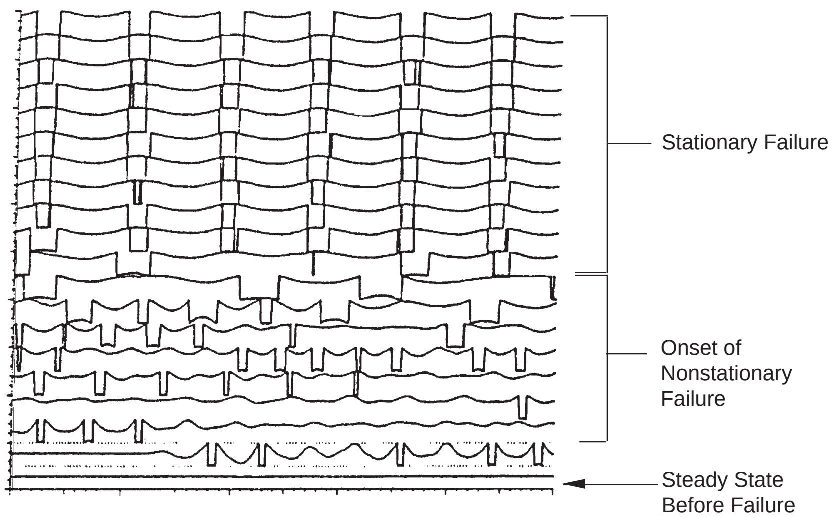
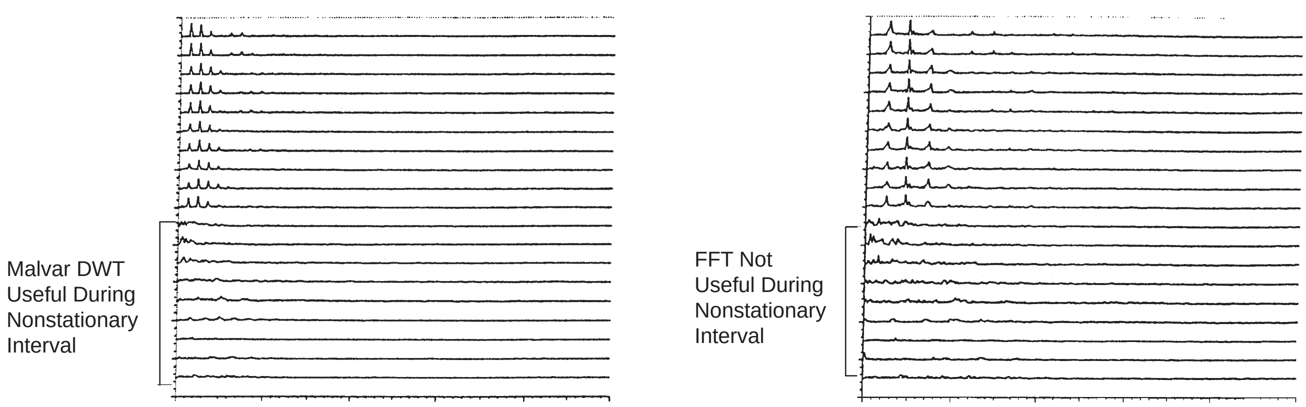
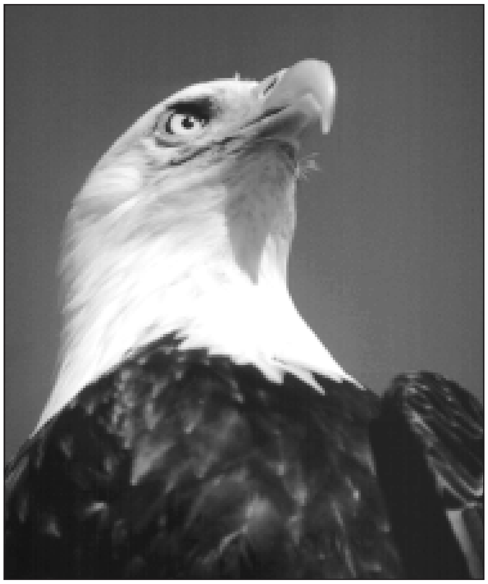
Participating Organizations: Dynacs Engineering Co., Inc. (R.N. Margasahayam) and Information Dynamics, Inc. (O.J. Varosi)



Time Domain Signal for Impending Bearing Failure



Comparison of DWT and FFT



Environmental Engineering

The John F. Kennedy Space Center (KSC) is located on the Merritt Island National Wildlife Refuge. Therefore, KSC has always approached its mission with an awareness of the impact on the environment. As a society, Americans have become increasingly concerned about the effect their actions have on the environment. With this awareness, KSC has increased its efforts to develop technologies that are environmentally oriented and proactive.

The projects presented this year cover a wide range of environmental technologies. An innovative method of scrubbing emissions from boilers is being developed that will reduce the amount of pollutants produced by power plants that burn fossil fuels. Also under development are methods to clean solvent-contaminated groundwater using in situ techniques that could reduce cleanup costs significantly.

Another area of interest is the geographical information required to make environmental decisions. A development is continuing to integrate geographical databases that provide easy access to the data used for planning purposes.

A project to plan controlled burns is also underway. The burns are an important tool for restoration of endangered species habitat and reduction of the danger of wildfire in operational areas.

Habitat Management and Ecological Risk Assessment Modeling

Monitoring and definition of habitat quality for biodiversity, threatened and endangered species, and environmental risk assessment require state-of-the-art information collection and analysis capabilities to minimize costs. Land management practices in many ecosystems, including KSC, are based on controlled burning for habitat enhancement and reduction of wildfire fuels. Available ecosystem models and fire and smoke models provide some guidance; however, no system currently exists that incorporates these tools with operational schedules such as a payload or vehicle processing system, real-time meteorological data, and remote sensing data for use in environmental decision support and risk assessment.

The approach to this project involves development of a diverse set of information tools including rule-based expert systems, numerical models, time series analysis, and fusion of a variety of data collection systems and databases to enhance the decision process. The project will:

- Provide data and information to optimize the management of resources at KSC and the Merritt Island National Wildlife Refuge.

- Incorporate NASA remote sensing and advanced GIS technology into local-scale, decisionmaking processes.

- Provide information and methods to reduce the potential for wildfires at KSC.

- Enhance NASA's capabilities to comply with Federal and State environmental laws such as the Endangered Species Act.

Key accomplishments:

- 1996: Obtained a high spectral resolution image of the KSC area using the NASA AVIRIS sensor. Initiated development of a deterministic model for estimating plant canopy biochemical and biophysical characteristics.
- 1997: Conducted an experimental control burn at KSC in association with the U.S. Fish and Wildlife Service, Los Alamos National Laboratory, United States Air Force, and Los Angeles County Fire Department to develop data on fire spread, intensity, and smoke production. Obtained high spatial resolution images (1 to 2 meters) of KSC. Obtained field measurements of plant canopy biophysical and biochemical features and plant canopy and leaf spectral characteristics for model development and parameterization.
- 1998: Developed a Web-based decision support tool that integrates payload schedules, Shuttle operations schedules, facility locations, and controlled burn prescriptions to minimize conflicts and maximize management of wildfire fuels and endangered wildlife habitat. Integrated plant biophysical features such as leaf area, leaf angle distribu-

tion, canopy closure, canopy height, and bottom reflectance into a two-flow irradiance model for radiative transfer in plant canopies.

Key milestones:

- 1996: Initiated GIS database integration in Oracle and development of image processing methods for use of high spectral resolution data in wildlife habitat mapping. Presented two papers at the Eco-Informa Conference in Orlando, Florida, on remote sensing modeling in plant canopies.
- 1997: Coordinated a multiagency experimental controlled burn to obtain data on fire and smoke behavior in coastal environments.
- 1998: Enhanced communications between the U.S. Fish and Wildlife Service and NASA Shuttle and Payloads Operations through development of a Web-based Schedule Analysis System for controlled burns at KSC.

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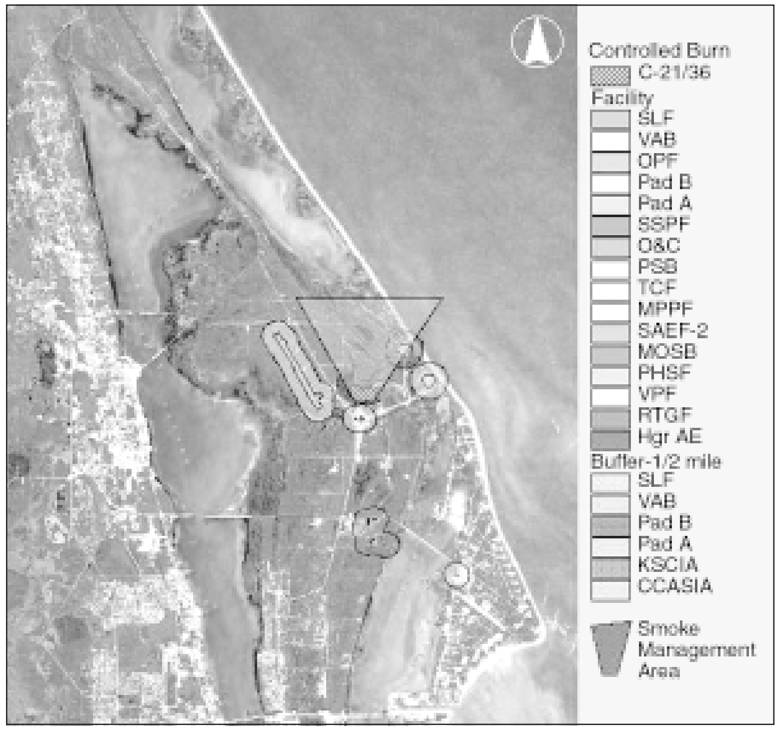
Participating Organization: Dynamac Corporation (R. Schaub and C. Hall)



Example Output From the Web-Based Decision Support Tool Showing Integration of Fire Management and KSC Operational Areas

- *Individual controlled burn events are plotted on separate maps.*
- *Only facilities with potentially critical smoke-sensitive operations are plotted.*
- *Half-mile buffer zones are plotted around each potentially critical smoke-sensitive operation to facilitate viewing of the large-scale map.*
- *Shuttle operations occur within the Shuttle Landing Facility, Vehicle Assembly Building, and launch pad regions.*
- *Payload operations occur within the KSC Industrial Area and Cape Canaveral Air Station Industrial Area.*
- *The smoke management area defines the region in which smoke may occur based on desired winds (smoke may also occur downwind of this area).*

Threatened and Endangered Species Monitoring

The habitats on KSC represent an area of biological diversity unsurpassed among Federal facilities. Under the Endangered Species Act and the National Environmental Policy Act, all operations require evaluation and impact minimization. Approximately 100 wildlife species on the Merritt Island National Wildlife Refuge are vulnerable to extinction. Monitoring focuses on combining field and remote sensing data with predictive / interpretive models on marine turtles, gopher tortoises, indigo snakes, wading birds, shorebirds, scrub jays, beach mice, and manatees. These studies contributed to more than 20 scientific journal articles and were used to develop rangewide species recovery efforts.

The influence of habitat on habitat use and demographic success is quantified at different spatial scales. Monte Carlo simulation models are used to quantify the influence of habitat quality, population size, and catastrophes on populations. Declining habitat quality was found to be a critical factor influencing extinction risk, so more frequently prescribed fires are needed.

Key accomplishments:

- 1991: Developed habitat maps of the most important areas at KSC for scrub jays, wading birds, and other species.
- 1992: Developed a scrub restoration and monitoring program.
- 1993: Developed a wetlands restoration program plan.
- 1994: Developed a KSC biological diversity evaluation summary.
- 1995: Developed techniques to map habitat suitability.
- 1996: Developed models to predict demographic success using maps.
- 1997: Tested the ability of maps and models to predict populations.
- 1998: Developed rapid assessment tools for environmental managers.

Key milestones:

- 1995: Population and habitat status trends summarized for gopher tortoise, wading birds, and scrub jays.
- 1996: Development of scrub jay population recovery strategy.
- 1997: Biological diversity prioritization analyses published.
- 1998: Habitat analysis procedures published.

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Participating Organization: Dynamac Corporation (D.R. Breininger)

Height Classes of Florida Scrub Jay Territories at KSC From 1988 to 1997
(Habitat classes are used for rapid assessment of scrub habitat quality.)

Height Class	Description	Minimum Mapping Units
Short	Entire territory was <120 centimeters (cm) tall	No patch taller than 120 cm was ≥0.4 hectare (ha) (1 acre)
Short / optimal mix	Territory was a mix of short (<120 cm) and optimal scrub (120 to 170 cm tall) and had no tall scrub (>170 cm tall)	At least 1 patch of optimal scrub was ≥0.4 ha and at least 1 patch of short scrub was ≥0.4 ha; no patch of tall scrub was ≥0.4 ha
Tall mix	Territory was a mix of tall scrub (>170 cm) and short and / or optimal scrub	At least 1 patch of tall scrub was ≥0.4 ha; at least 1 patch of short or optimal scrub was ≥0.4 ha
Tall	Entire territory was >170 cm tall	No scrub <170 cm tall was ≥0.4 ha

Florida Scrub Jay Demography and Densities Among Scrub Height Classes
That Resulted From Fire Patterns at KSC From 1988 to 1997
(Values in parentheses are the mean and sample sizes.)

	All Short (<120 cm tall)	Short / Optimal Mix	Tall Mix	All Tall (>170 cm tall)	Unburned Archbold*	Optimal Archbold*
Fledglings / pairs	1.05 (63)	1.41 (101)	0.99 (178)	0.25 (36)	1.58	1.97
Juveniles / pair	0.46 (65)	0.88 (103)	0.41 (181)	0.08 (37)	0.8	1.23
Yearlings / pair	0.23 (65)	0.61 (103)	0.28 (181)	0.08 (37)	0.36	0.68
Breeder survival	0.76 (131)	0.81 (212)	0.80 (366)	0.77 (77)	0.72	0.79
Fledgling survival	0.20 (66)	0.43 (143)	0.28 (178)	0.33 (9)	0.23	0.31
Demographic performance**	-0.28 (65)	0.21 (103)	-0.16 (181)	-0.41 (37)		
Family size	2.66 (65)	3.05 (103)	2.86 (181)	2.40 (37)		3.00
Territory size (ha)	7.37 (65)	9.15 (103)	6.25 (181)	4.69 (37)		9.00
Density (jays / ha)	0.51 (65)	0.45 (103)	0.62 (181)	0.78 (37)		

** Woolfenden and Fitzpatrick (1984, 1991)*
*** Yearling production; breeder mortality*

Pilot-Scale Evaluation of a New Technology To Control NO_x Emissions From Stationary Combustion Sources

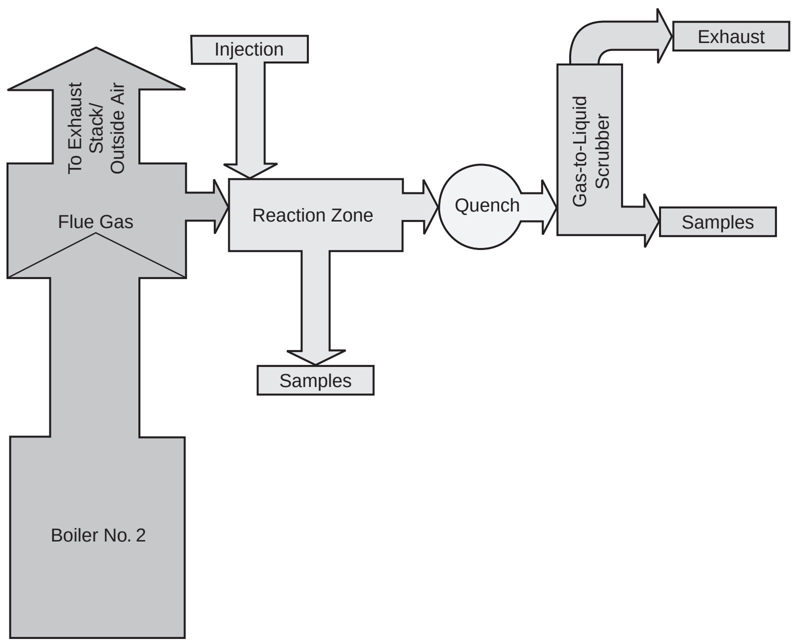

Figure 1. Conceptual Design of the System

As a result of the implementation of the Clean Air Act Amendments of 1990, parties responsible for stationary combustion sources emitting nitrogen oxides (NO_x) are looking for methods to meet regulatory requirements. NASA entered into a 3-year cooperative agreement with the University of Central Florida (UCF) to perform a pilot-scale study of a new control technology for NO_x emissions from industrial-sized boilers (see figure 1). Hydrogen peroxide is injected into the flue gas stream to oxidize the NO_x to nitrogen acids. This step is followed by liquid scrubbing, which produces a nitrogen-rich, water-based waste stream. This study was a scale-up on the order of 1,000 times from lab-scale studies previously conducted at UCF. A scale-up from this pilot plant to a power plant would be on the same order of magnitude. NASA and UCF are joined by industry partner EKA Chemicals, Inc., on this research and development project. EKA Chemicals brings to the project extensive engineering expertise on various hydrogen peroxide applications.

A data acquisition system using a personal computer and LabView software (see figure 2) is tied into the entire system to allow for control, automatic emergency shutdown, and recording of 21 points at a rate of 1 sample per second. Over 100 tests were conducted during the past year resulting in over 6 million data points.

The primary result from the first phase of this study is shown in figure 3. A feasibility study conducted by UCF researchers indicated this technology would be competitive with technology (selective catalytic reduction) currently available to power plants if nitric oxide (NO) conversion efficiencies above 90 percent could be achieved at a hydrogen peroxide feed rate of 1.37 moles of hydrogen peroxide per mole of NO converted (to acid). The Phase I results of this technology show 96 percent NO conversions were achieved at a molar ratio of 1.0.

Key accomplishments:

- 1997: Phase I design, installation, and preliminary testing complete.
- 1998: Phase I testing, data analysis, and reports complete. Presentations at the Air and Waste Management Association's Pacific Northwest and Southern States section meetings.

Key milestones:

- 1999: Present Phase I results at the Air and Waste Management Association's annual conference. Phase II design, testing, data analysis, and reports to be completed.

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Participating Organizations: University of Central Florida (Dr. C.D. Cooper; Dr. C.A. Clausen, III; and Dr. J.D. Dietz) and EKA Chemicals, Inc. (J. Tenney and D. Bonislawski)

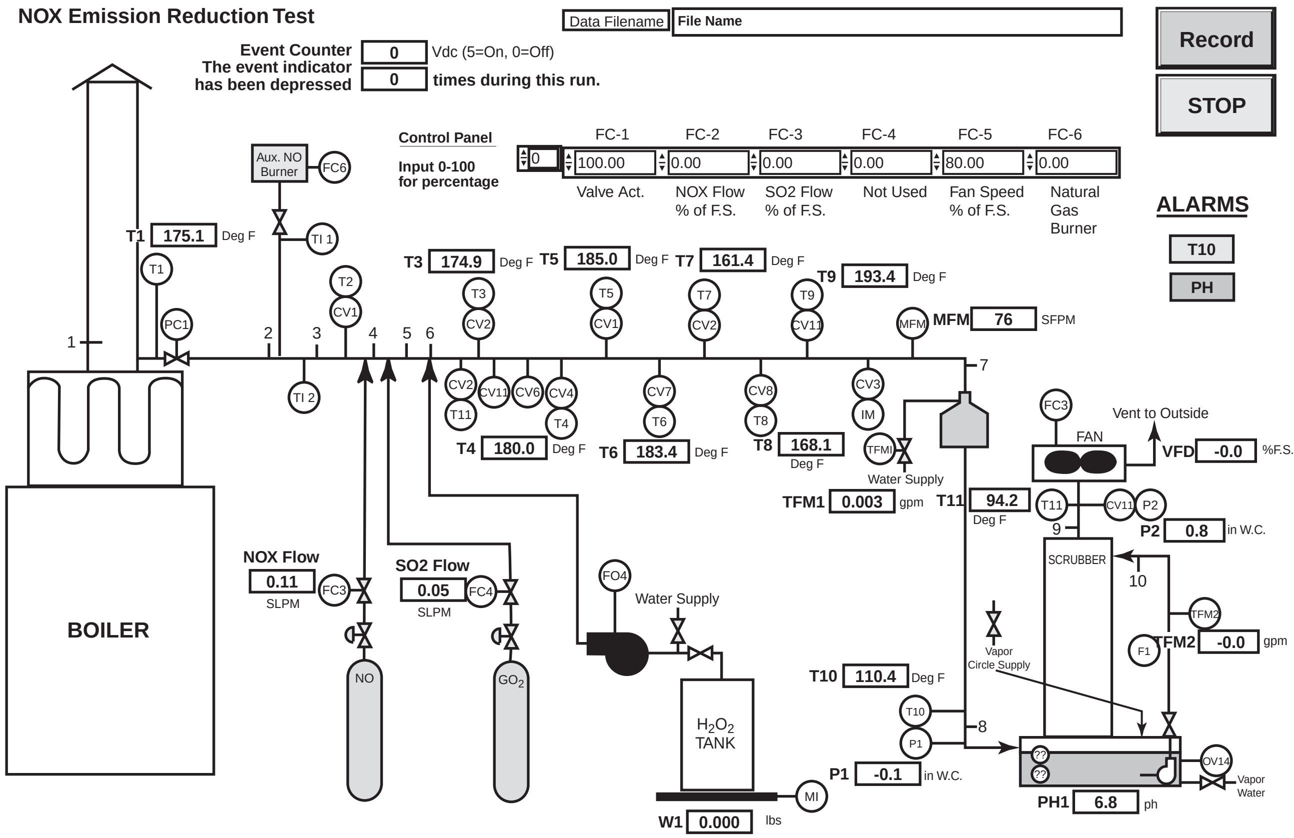


Figure 2. Front Panel of the PC Software Used To Collect Data From Points in the System

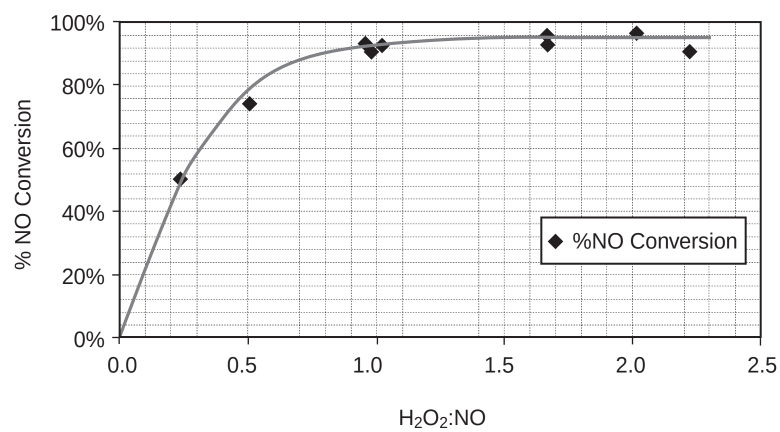


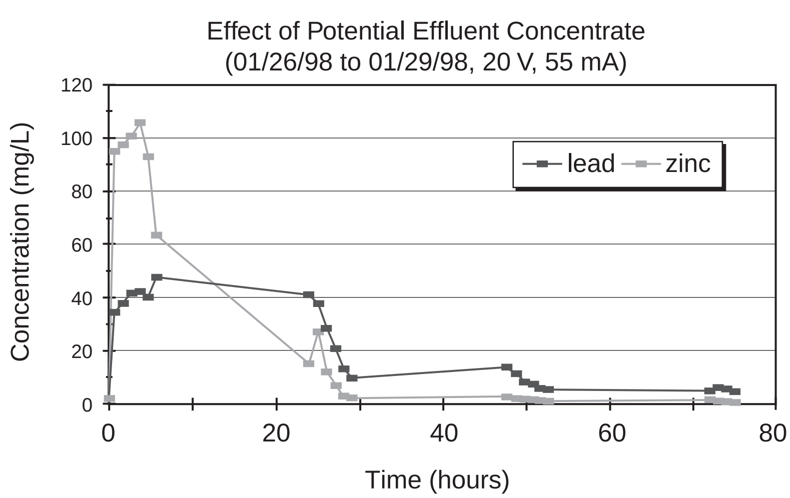
Figure 3. Percent NO Conversions for Inlet NO_x of 400 ppm and Tests Conducted Within the Temperature Range of 912 to 939°F

Development of an In Situ Technique for Electrokinetic Remediation of Soils Contaminated With Heavy Metals

Because of the costs and limitations of the current remediation methods, considerable effort is being directed toward the development of in situ treatment methods. An innovative method, electrokinetic remediation, offers a way for soils with a variety of hydraulic conductivities to be remediated in situ. Electrokinetics has been used for decades to remove water from soils and in the oil recovery industry, but in situ applications to remediate contaminated soils is new. Electrokinetics is a process that separates and extracts certain heavy metals, radionuclides, and organic contaminants from saturated or unsaturated soils, sludges, and sediments. A low-intensity direct current is applied across electrode pairs that have been implanted in the ground on each side of the contaminated soil mass. The electrical current causes electroosmosis, ion migration, and electrophoresis, which removes bound ions from solid particles and moves the aqueous phase contaminants in the subsurface from one electrode to the other.

Laboratory studies at the University of Central Florida have been used to evaluate the efficiency of this process and its likelihood of success at KSC. Initially, studies were carried out in a 12-inch-long, 4-inch-diameter Plexiglas cell that was loaded with 2,000 grams (dry weight) of a synthetic soil mixture. The soil was spiked with lead (Pb) and zinc (Zn) to concentrations up to 2,000 milligrams per kilogram of soil, then the metals were immobilized using a sodium hydroxide rinse. Graphite electrodes (placed either perpendicular or parallel to the flow) were used with applied voltages ranging from 15 to 48 volts and a constant current of 100 milliamperes. A conditioning solution of dilute lactic (0.1 to 0.5 percent) acid was introduced at the anode and removed at the cathode. This conditioning fluid served as an additional liquid for current flow and to keep the pH in an acceptable operating range near the cathode region.

It was shown from these experiments that both Pb and Zn were quickly removed to 10 percent of their original concentrations (within 7 days). A comparison of the ion removal effi-



Lead and Zinc Concentrations in Effluent With Applied Voltage ciency with and without an applied voltage is shown in the figure. As voltage was applied, the concentrations of Pb and Zn in the effluent solution increased. In another experiment, removal efficiency was shown to be dependent on the addition of lactic acid. With only water as a conditioning fluid, extraction efficiency was low but, with the introduction of a very low concentration of lactic acid (as low as 0.1 percent), the ion concentrations in the effluent solution began to increase dramatically.

The effects of electrode position were studied by constructing a rectangular cell and positioning two pairs of electrodes at different distances. Experiments have shown that electrodes positioned 18 to 22 inches apart provided effective movement of ions in various soil types. This information was used to develop the most efficient electrode arrangement for a field application. A hexagonal array of anodes with a single cathode placed directly in the center was found to yield efficient removal of metal ions while reducing the number of pumping stations (cathodes) required.

Additionally, a telephone line, an extension cord, and various types of weathered pipe were buried in the soil for a period of 3 weeks to determine if the process would interfere with communications or other subsurface electrical conduits. During this time, there was no disruption of communication or electrical use and the pipes showed no pitting.

Key accomplishments:

- June 1998: Laboratory studies were completed.
- August 1998: Field demonstration site was selected at KSC.
- September 1998: Field design was completed.

Key milestone:

- Laboratory data used to design the field demonstration was completed, with field implementation to begin in January 1999.

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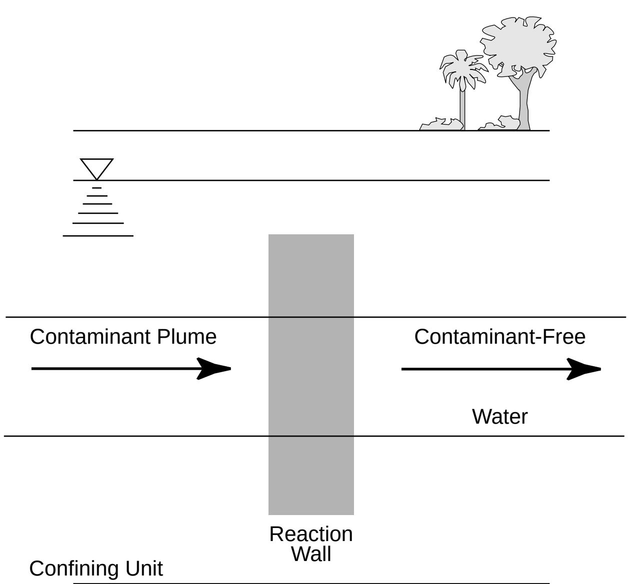
Participating Organization: University of Central Florida (Department of Chemistry and Departments of Civil and Environmental Engineering)

Enhanced In Situ Zero-Valent Metal Permeable Treatment Walls

Chlorinated solvents have been widely used by NASA and others in the aerospace industry for over three decades. They have primarily been used as nonflammable degreasers and dryers for electronic parts. Historically, the disposal practices for spent chlorinated solvents included discharges to surface water and groundwater. It is, therefore, not surprising to find groundwater solvent contamination at 791 of the 1,300 National Priority List sites.

To date, the most commonly used treatment method for the cleanup of chlorinated solvents has been the pump-and-treat method. With this method, the groundwater is pumped to the surface, and the contaminants are either oxidized or removed with an air stripper. Although the pump-and-treat method was originally thought to be a competent remediation tool, it has shown itself to be most effective in groundwater plume capture and containment. In general, it can be said that the significant operation and maintenance costs associated with pump-and-treat systems eliminate this remediation technique for large-scale cleanups.



Permeable Treatment Wall

Within the last 5 years, a substantial amount of research focused on the use of zero-valent metals to catalytically enhance the abiotic degradation of chlorinated solvents. Of the zero-valent metals available and tested (iron, cobalt, zinc, and nickel prophyrins), iron is the most attractive due to its low cost and availability. With this technology, iron filings are mixed with sand and placed below the land surface and downgradient of the contaminant source. Natural groundwater gradient transports the contaminated groundwater through the iron / sand permeable treatment wall. As the contaminant comes into contact with the iron filings, catalytic degradation of the chlorinated species begins with what appears to be the simultaneous oxidation of iron by water and the subsequent reductive dechlorination of the contaminant.

In March 1998, a 40-foot-long and 4-foot-wide permeable treatment wall was installed at Launch Complex 34 at Cape Canaveral Air Station to a depth of 40 feet below land surface. The demonstration project tested a new construction technique that uses deep-soil mixing with vibro-installation as a method for getting the reactive iron into the subsurface. Preliminary analytical results indicate that contaminants such as cis-1,2 dichloride have dropped from an inlet concentration of greater than 13,000 µg/L to less than 60 µg/L, which is the Florida drinking water standard.

Key accomplishments:

- September 1997: Patent application submitted.
- August 1997: Field-scale design completed.
- March 1998: Construction completed.

Key milestones:

- Wall monitoring will continue over the next year with particular attention on contaminant degradation and groundwater geochemistry changes.
- Ultrasound field testing will be conducted on the wall during the next year (see the KSC Research and Technology 1997 Annual Report), and a tracer study will be initiated to examine groundwater flow patterns.

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Participating Organization: University of Central Florida (Departments of Civil and Environmental Engineering and the Department of Chemistry)

Field Application of Deep Soil Mixing

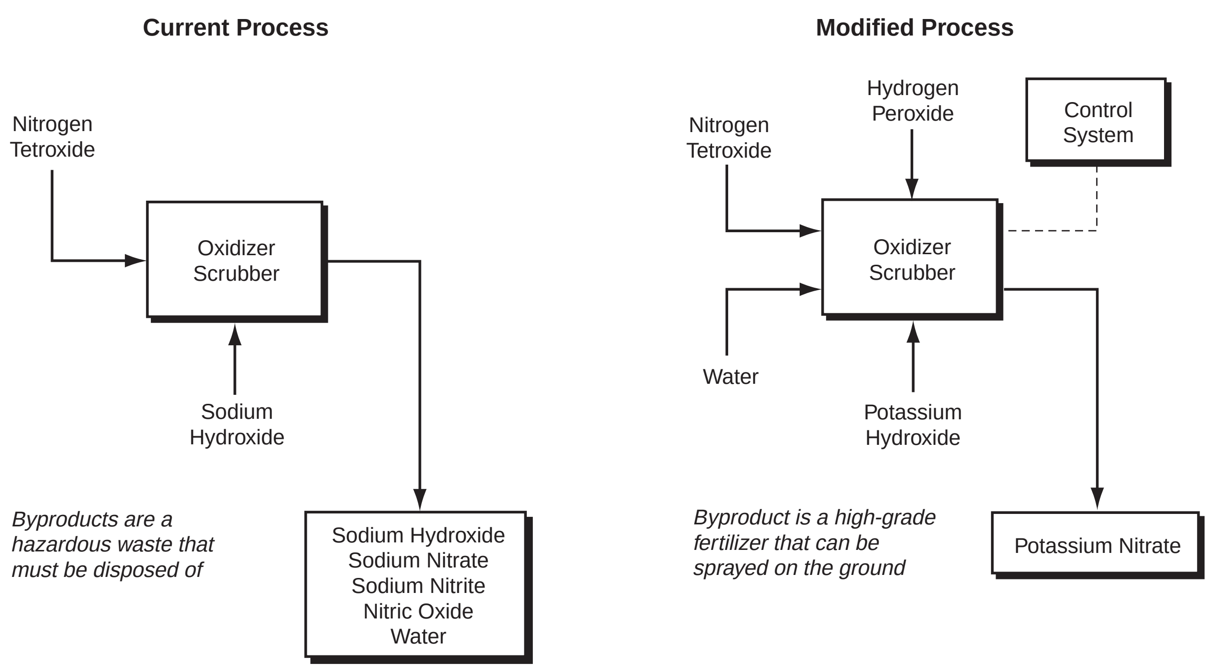
Field Application of Vibroinsulation

Installation of a New Scrubber Liquor for the Nitrogen Tetroxide Scrubbers That Produces a Commercial Fertilizer

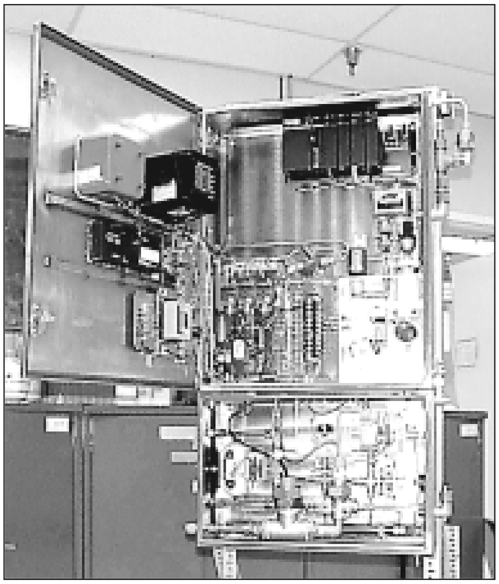
NASA, in conjunction with Dynacs Engineering Co., Inc., and United Space Alliance, is installing a prototype of the new scrubber-liquor control system that converts nitrogen tetroxide (the hypergolic oxidizer) to a fertilizer. The fertilizer produced by this process will be used on the citrus groves at KSC. This project is in Phase V of a five-phase program to comply with Executive Orders 12856 and 12873, the Right-to-Know Laws, and the Recycling and Waste Prevention Law. Hypergolic propellants are used in spacecraft such as the Space Shuttle, Titan IV, Delta II, and other vehicles and payloads launched at KSC and Cape Canaveral Air Station. Monomethylhydrazine (MMH), nitrogen tetroxide (N_2O_4 or NTO), and hydrazine (N_2H_4 or HZ) are the main propellants of concern. Fueling and deservicing spacecraft constitute the bulk of operations in which environmental emissions of nitrogen oxide (NO_x) occur. The scrubber liquor waste generated by the oxidizer scrubbers (approximately 311,000 pounds per year) is the second largest waste stream at KSC. The disposal cost for this oxidizer scrubber liquor waste is approximately $0.227 per pound or $70,600 a year.

The new process will convert the scrubber liquor to a high-grade fertilizer (see the flowchart). The process reacts N_2O_4 with hydrogen peroxide and potassium hydroxide and produces potassium nitrate, a major ingredient in commercial fertilizers. This process avoids the generation of the hazardous wastes, which occurs when sodium hydroxide is used as the scrubber liquor. A patent application that covers the process has been filed with the U.S. Patent and Trademark Office.

A feature of the new process is lower NO_x emissions, since the new scrubber is more efficient at capturing nitrogen tetroxide than the current scrubber liquor. For example, when the two scrubber liquors were compared under similar test conditions, the emissions from the new scrubber liquor were only 1 to 10 percent of the emissions from the current scrubber liquor. A major effect of lower NO_x emission will be to reduce the size of the area around the oxidizer scrubbers that must



Process Converting Nitrogen Tetroxide Wastes to Potassium Nitrate, a Commercial Fertilizer



Control Panel for the Oxidizer Scrubber Control System

be cleared during operations, thus reducing the impact of toxic hypergolic oxidizer emissions on adjacent operations.

The new scrubber liquor and control system was tested with nitrogen dioxide (NO_2) concentrations from low parts per million to pure vapor. To simulate operations at KSC where aspirators are used to capture NO_2 vapor, up to 500 standard cubic feet per minute of gaseous nitrogen (GN_2) were added to the NO_2 stream. In addition, approximately 90 pounds of oxidizer (vapor and liquid) were added over a 1- to 9-minute period to the scrubber. Under all of these test conditions, the new scrubber-liquor system performed well and produced lower emissions. The only problem encountered during the field tests, which will require slight modifications to the scrubber, was due to inadequate mixing in the scrubber sump. These mixing problems are being corrected during the current installation by changing the point of addition of the reagents.

In summary, this change in the scrubber liquor has eliminated the second largest hazardous waste stream at KSC and produced a product that is approved for application as fertilizer to the lawns and citrus groves at KSC. This new scrubber liquor is a 15-weight-percent potassium nitrate solution with 0- to 1-weight-percent hydrogen peroxide and a pH of 7. The system is more efficient and less expensive than the current 25-weight-percent sodium hydroxide, when all factors including waste disposal, fertilizer replacement, and handling a hazardous waste (the spent oxidizer scrubber liquor) are considered.

Key accomplishments:

- Developed a method to eliminate the second largest waste stream at KSC (oxidizer scrubber-liquor waste).
- Developed internal diagnostics that monitor the performance of the control system.
- Developed a production process for potassium nitrate, a fertilizer currently purchased by KSC for use on lawns and citrus groves.
- Demonstrated that the process control system is robust and can withstand field operations.
- Demonstrated that the scrubber liquor is more efficient with only 1 to 10 percent of the emissions found with the current 25-weight-percent sodium hydroxide scrubber liquor.

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Participating Organization: Dynacs Engineering Co., Inc. (C.F. Parrish, C.J. Schwindt, T.R. Hodge, and P.H. Gamble)

Less Toxic Orbiter TPS Rewaterproofing Agent Study

The present orbiter Thermal Protection System (TPS) rewaterproofing agent, dimethylethoxysilane (DMES), performs exceptionally well in preventing water absorption in ceramic, silica-based materials. DMES reacts with the surface of glass fibers in the tile or the fabric in blankets and deposits a film of organic material that repels water. Although the tiles and blankets are waterproofed when fabricated, reentry burns out the agent when temperatures reach 1,050 degrees Fahrenheit or greater, thus requiring rewaterproofing after each Shuttle mission. The action of waterproofing results from the bonding of dimethyl silanol, an unstable reaction intermediate, with hydroxyls on the silica fiber surfaces. When a typical 6- by 6- by 2-inch Orbiter tile is rewaterproofed, 2 cubic centimeters (cm^3) of DMES is injected with a needleless gun into a small hole in the center of the tile.

The threshold limit value (TLV) for DMES is 0.5 part per million (ppm). Some workers complained of throat irritation and light headedness after being exposed to low-ppm levels of DMES. Orbiter Processing Facility (OPF) ventilation system modifications were made to minimize this problem. In the course of applying DMES before a launch, toxic vapor emissions to the OPF high bay are significant enough to require the use of protective gear and a breathing apparatus. The bay must be cleared of all nonessential personnel and cannot be reopened for other vehicle work until the DMES vapors measure 0.5 ppm. Therefore, rewaterproofing must be performed on the third work shift and on weekends.

A KSC Shuttle upgrades project was initiated to find an alternative, less toxic rewaterproofing agent to DMES but maintain acceptable waterproofing performance. Screening tests were performed with 2-inch LI-900 tile coupon cubes by injecting them with 0.5 cm^3 of waterproofing agent. Also, material compatibility tests were performed with both types of room-temperature-vulcanizing (RTV) adhesives used in the orbiter TPS bonding process. The coupon screening tests uncovered no waterproofing agent better than DMES. However, five carrier solvents [n-pentane; 2,3-dimethlybutane (DMB); 2,3-dimethyl pentane (DMP); acetone; and perfluorocyclobutane (PFCB)] were down-selected to dilute the DMES (decrease its effective toxicity) and to enhance its dispersion throughout the silica fibers in the orbiter TPS. Solutions of DMES in these solvents were injected into 6- by 6- by 2-inch deep LI-900, reaction-cured glass (RCG) coated orbiter tiles at various concentrations, and the resulting water uptake was measured. Rewaterproofing residue weight pickup was also measured over a number of cycles, and the results after several injections showed insignificant accumulative weight gains on the order of 0.2 percent or less. Another test series, tile off-gassing detection, was performed to measure the concentration and duration of the emitted vapors. RCG-coated tiles were injected with DMES / solvent mixtures while the tiles were in a Plexiglas chamber. This procedure was used to compare the emission and decay rate of 100-percent DMES versus DMES / solvent combinations using the Foxboro Miran 203 meter. A Fourier Transform Infrared (FTIR) method (measures each constituent separately), previously developed by the Toxic Vapor Detection Laboratory for DMES carts, was used to measure the amount of solvent (ppm) detected when the Miran meter measured 0.5 ppm. This data was compared to the TLV of the solvent to determine if concentrations were acceptable.

Flexible insulation blankets were also injected with the above solutions of DMES using a needle gun. After injection, several droplets of water were placed on the surfaces of the blankets and observed for absorption. Two tests each were performed with 20-percent DMES solutions in DMP, DMB, and n-pentane. Two tests were also performed with 10-percent DMES in PFCB. All blanket rewaterproofing experiments were successful in preventing water droplets from entering the blanket surface.

Overall, DMES solutions at 20 percent in solvents performed successfully in tiles (i.e., the water absorbed in tiles was less than 5 percent of the tile weight). All solvents were also compatible with both RTV's. N-pentane was finally selected as the solvent for DMES due to its low toxicity and low cost, combined with its excellent repeatability with DMES. In tests comparing off-gassing data, a TLV equal to 0.5 ppm was achieved 44 percent faster in a tile injected with 20/80 DMES/n-pentane versus 100-percent DMES (5.3 hours versus 9.5 hours) (see the figures).

In conclusion, n-pentane is recommended as the carrier solvent for DMES to decrease the overall agent toxicity. It has a low toxicity (TLV of 600 ppm), low cost ($4 per gallon), and excellent repeatability when combined with DMES. The new recommended rewaterproofing combination is a 20/80 DMES/n-pentane mix. The benefits of using the recommended mix are: (1) a decrease of DMES vapors in the OPF; (2) a reduction in protective equipment safety criteria; (3) a decrease in the cost to perform rewaterproofing due to reduced safety requirements, fan usage, and the cost of chemicals; (4) a chemical cost saving estimated at $147,200 per year (based on the current 100-percent DMES versus 20/80 DMES/n-pentane mix for eight flows per year; (5) the number of clearances of the high bay could be minimized, thus reducing rewaterproofing flow impacts to long-term program manifest requirements; and (6) greater flexibility in the rewaterproofing process.

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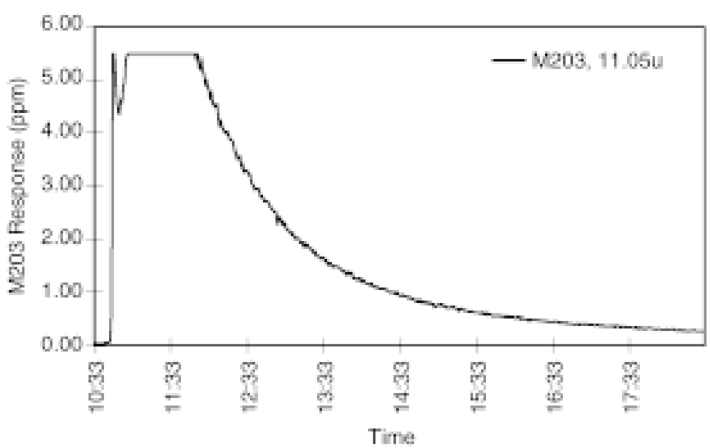
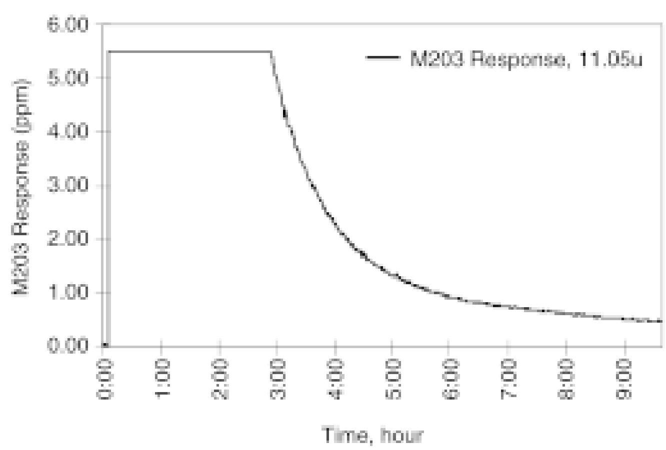
Participating Organizations: NASA-KSC (F. Jones, M. Cardinale, D. Lueck, and J. Branard); Comprehensive Health Services, Inc. (J. Taffer); Boeing-Seattle (C. Newquist); Dynacs Engineering Co., Inc. (R. Barile, N. Bardel, J. Curran, T. Hodge, P. Gamble, C. Mattson, B. Meneghelli, and C. Parrish); NASA-JSC (C. Schomburg); BNA-Downey (D. Bell and M. Gubbert); Ames-Elorett (J. Pallix); United Space Alliance (S. Nickell, G. Powers, R. Loeffler, and O. Torres); and KSC-BNA (R. Frittier)



Tile Injection, 2 cm^3 20-Percent DMES in n-Pentane, 50 Liters per Minute, M203



Tile Injection, 2 cm^3 Pure DMES, 50 Liters per Minute, M203

Supercritical Air-Powered Environmental Control Unit for SCAPE

KSC uses the Self-Contained Atmospheric Protective Ensemble (SCAPE) for the safeguard of personnel handling rocket propellants. The existing configuration relies upon the use of a liquid-air-powered environmental control unit (ECU) that has seen nearly 30 years of successful operation in support of NASA and Air Force missions. The Category I configuration of this suit provides the user with totally encapsulating protection for over 2 hours. However, several problems in the use of liquid air have been identified and remain unsolved. Training and operational monitoring and constraints have safely controlled these problems to date.

A new initiative has begun for the development of an Advanced Protective Suit (APS) that will meet future mission support needs in an environment that is expected to impose even lower toxic threshold limit values for human exposures. Initial efforts have focused on the remediation of liquid air system problems. Specifically, these problems are dependent upon (1) an upright dewar (storage vessel) attitude, (2) an unstable or nonhomogeneous liquid mix where the liquid nitrogen component boils off before the oxygen component, and (3) the determination of dewar quantity throughout the service life when the ECU is on a person's back and in motion, which often is in an unusual attitude.

A feasibility study of the storage and use of air in a supercritical phase has been successfully conducted in the Biomedical Laboratory at KSC. This development was an extension of technology gained in a Small Business Innovation Research project conducted by Aerospace Design and Development, Inc., where a supercritical air, positive pressure demand, self-contained breathing apparatus was designed. The SCAPE ECU is a constant-flow system that supports respiration and cooling of the user. The new ECU stores 6.5 pounds of supercritical air in a high-efficiency dewar and provides the air, after conditioning, to the suit air distribution manifold. The prototype design will be further modified to employ a more effective liquid-cooled garment in place of air cooling. Problems with attitude sensitivity, stability of the gas, and quantity measure have been solved in this relatively lower pressure, cryogenic, gaseous system.

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Advanced Software

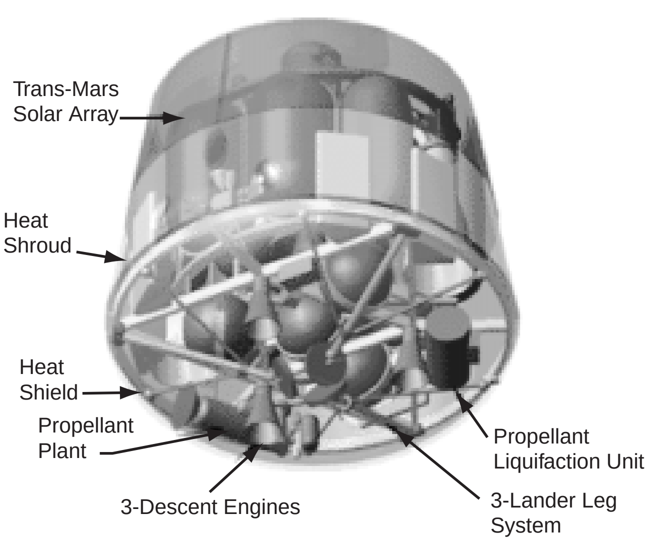
The goal of the Advanced Software program at the John F. Kennedy Space Center (KSC) is to investigate and develop cutting-edge advanced software technologies in support of launch and ground processing functions. New software technologies are being developed to improve capabilities and reduce operations and maintenance costs for present and future vehicles, payloads, and launch systems.

To meet the challenge of becoming more efficient in all aspects of KSC work, advanced software technologies are being developed from the expanding technological base; and these technologies are being used to improve performance, save time, and increase productivity. This year's Advanced Software program employs a broad range of disciplines and technologies, including programs that process vast quantities of data and make the data available for Operation's use through tools (such as the Internet), model-based reasoning systems to autonomously manage complex chemical processing systems, and advanced mathematical techniques that enhance capabilities for imaging and wave analysis.

Mars ISPP Autonomous Controller

KSC's Roadmap to the Future places an emphasis on NASA's efforts to develop the technologies necessary to send a manned mission to Mars. A key element of NASA's strategy to send a manned mission to Mars is the utilization of resources present in the Martian environment. This element is known as In Situ Resource Utilization (ISRU). One component of ISRU is the production of fuel and oxidizer for the Crew Ascent Vehicle. This is called In Situ Propellant Production (ISPP).

Communication lags between the Earth and Mars make it impractical to control the ISPP plant directly from Earth. Therefore, autonomous control software is necessary to operate the ISPP plant with little or no help from ground controllers. Since the plant has to operate for over a year, the control software must be adaptive. It must be able to handle component failures as well as degradation of the chemical processes. Because of the broad applicability of autonomous control, this project will help increase the body of knowledge for all control system needs — whether targeted at manned missions to Mars or ground launch systems for the Shuttle.



Mars ISRU Sample Return

Mars Entry Vehicle

An important aspect of this project is the partnerships with other centers that make it possible. Johnson Space Center (JSC) is the lead center for the development of ISRU technologies, but they are partnering with other centers to capitalize on their areas of expertise. For the ISPP project, both Ames Research Center (ARC) and KSC have experience with artificial intelligence (AI) software for autonomous control. For the ISPP effort, KSC will create the AI program for autonomous control using a language created by ARC. As the project progresses, KSC will help ARC extend the capabilities of their language to incorporate more dynamic process modeling capabilities needed to fully implement the ISPP controller.

The primary objective for the Mars ISPP autonomous controller project is to develop autonomous control software that will operate a prototype ISPP plant constructed at JSC. However, JSC is still experimenting with several techniques for ISPP, so immediate pursuit of this objective is premature. In order to elevate AI technology to the necessary readiness level, a simplified autonomous control package using the ARC-developed language will be created to operate a simulated ISPP plant. This will facilitate development of software modules to communicate with the user and interface with the hardware. It will also help identify enhancements the ARC language needed to handle quantitative modeling issues presented by ISPP.

As these enhancement needs are identified, KSC will work with ARC to develop solutions. Once the enhancements are completed, KSC will use this enhanced language to create a comprehensive autonomous controller for the ISPP simulation. When the JSC ISPP prototype is completed, KSC will deliver the autonomous controller software to JSC, where it will be integrated with their adjustable autonomy test bed. KSC will make all the necessary modifications to adapt the autonomous controller to the JSC prototype hardware.

Key accomplishment:

- 1998: Demonstration of the circuit breaker and power distribution control system using model-based reasoning.

Key milestones:

- 1999: Demonstration of a preliminary ISPP monitoring and control system. Continue the development of ISPP monitoring capabilities. Expand the functionality to include quantitative and semiqualitative diagnostic and control functions.

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JView Internet Display of Shuttle Real-Time Data Using Java

The rapid growth of Internet access to information since 1995 has resulted in a significant paradigm shift in how information is accessed and the resulting expectations of users concerning information availability and ease of access. During the past 4 years, however, the type of information accessed on the Web has primarily been static in nature. The recent availability of Java has enabled a new class of applications that contains dynamic content and real-time data sources over the Internet. The use of Java for display of real-time Shuttle data as presented here represents a demonstration of how existing applications at KSC could be implemented using the Internet paradigm.

The current display of real-time Shuttle data involves a centralized server that receives data from the common data buffer and sends it to Intel™ processor PC clients who display it on predefined screens. PC clients use MS-DOS™ and character-based graphics with close ties to specific hardware, operating systems, network interfaces, etc. This implementation has no inherent security or ability to work globally, and the PC becomes dedicated to the display of data.

Using Java presents an ideal approach since much of the effort in establishing a client/server connection across a local or wide area network is already provided. Java supports implementing solutions as both applications and applets. The applet was used for the client-side display of Shuttle screens. The advantages of a Java-based solution are geographic independence; shorter development and training; write once, run anywhere applications; security; ease of administration; and multiple Shuttle displays.

The initial goal for the Internet Display of Shuttle Real-Time Data Using Java project was to demonstrate the feasibility of using Java and a commercial off-the-shelf (COTS) Web browser to display real-time Space Shuttle data, equivalent to the current application called PCGOAL. This was successfully demonstrated in the Automated and Intelligent Systems Computer Laboratory, where multiple computers of differing configurations displayed the following data: (1) hardware (Intel X86, Sun SPARC, and Motorola POWER PC), (2) operating system (Solaris, SunOS, WindowsNT, Windows95/98, and Macintosh Finder), and (3) Web browser (Netscape Navigator, Version 4.0+; and Internet Explorer, Version 4.0+).

In addition to demonstrating a single Web browser/JView client display on each of seven systems simultaneously, a test of nine different Web browser/JView client displays on a single WindowsNT system was possible. The best display results were achieved using version 4.0 of Netscape Navigator and Internet Explorer, which contain a just-in-time compiler for Java, greatly improving display performance by at least an order of magnitude.

The current phase involves taking the proof-of-concept work completed earlier and applying the technology to solve actual monitoring requirements at KSC and other NASA centers. In conjunction with this implementation, additional system design and testing will be accomplished in the areas of (1) tuning the applet (client) and application (server) for maximum performance; (2) establishing robust extensible class libraries of reusable software components, applicable for present and future projects; (3) analyzing network bandwidth utilization to support the maximum number of clients; (4) providing direct connections to data sources, both real-time and historical; (5) developing graphical user interfaces with increased display options and resizable screens; (6) developing advanced plotting capabilities using Java "swing" technology to maximize extensibility; and (7) extensive system level testing and certification.

The viability of using Java, a relatively new language/runtime environment, in conjunction with a COTS Web browser to rapidly develop and deploy process monitoring and control applications, has been demonstrated. This new technology has the potential of significantly reducing the time and cost of developing and maintaining applications, given the flexibility to write the application once and run it anywhere. Use of COTS systems and a Web browser minimizes the cost, configuration, and training issues associated with deployment of new applications. This type of solution has great potential applicability at KSC, other NASA centers, and industry technology transfer in the areas of: (1) training using live or simulated data sources, (2) real-time monitoring of live Space Shuttle data (or any type of data source), (3) expert/advisory systems for predictive analysis, and (4) historical review for postmission data analysis and review.

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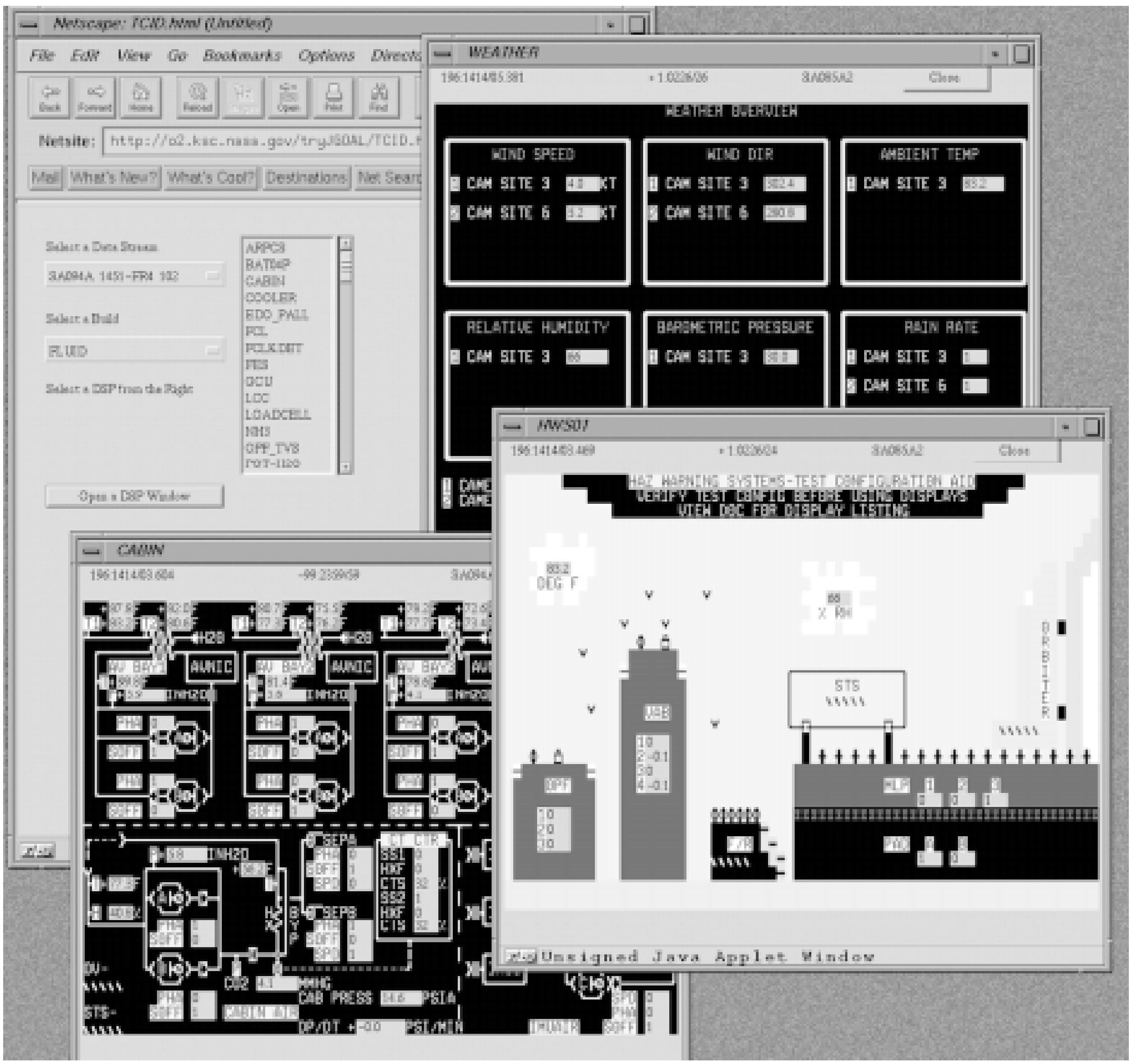
Participating Organizations: Dynacs Engineering Co., Inc. (J.M. Dockendorf, C.H. Goodrich, S.R. Beltz, and M.S. Long), Florida Institute of Technology (Dr. R. Stansifer), Princeton University (K. Gillett), and Duke University (W. Riddle)



Automation of OMI S9002 for Orbiter Processing

The term S9002 refers to the operations and maintenance instruction (OMI) for the Posttest Data Review by responsible engineers of sensor data collected during the certain critical processing of orbiters from the time of landing up to and including launch. OMI S9002 includes a number of subordinate OMI's. One is S0007, the OMI for orbiter launch, which includes the production of roughly 2,500 sensor readings (data products) that require review by engineers responsible for each of the orbiter's subsystems and supporting subsystems (e.g., main engines, hazardous gas systems, auxiliary power units, etc.).

Data products are hard-copy printouts of charts, plots, graphs, or listings for specific sets of periodic sensor readings, usually specified for a predetermined timespan, that include a start event and stop event. Some data products are also run on demand at the request of a responsible subsystem engineer (typically in the firing room) who specifies which data product to produce and provides specific start and stop times. These data products are termed "will calls."

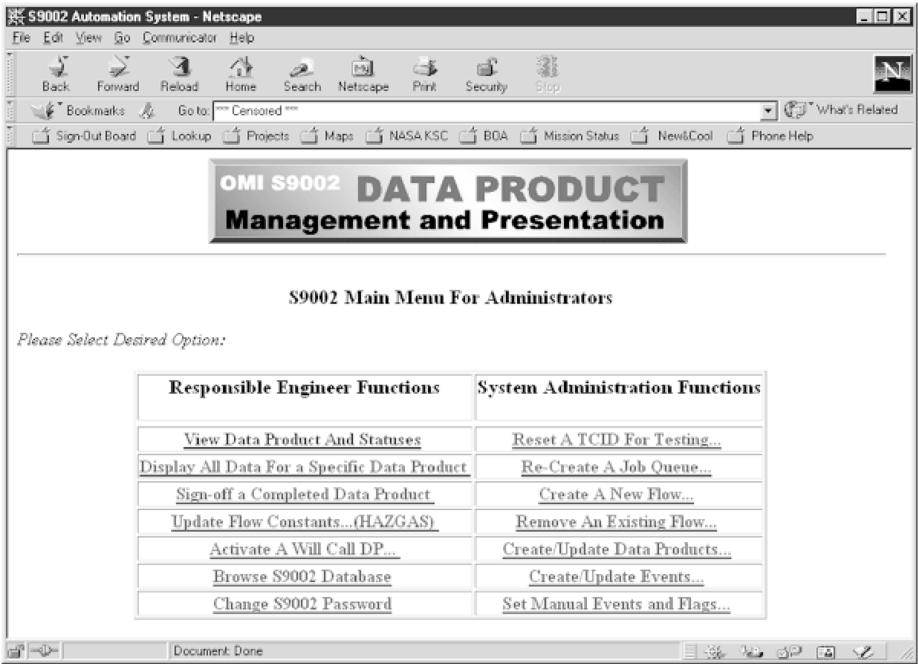
The present S0007 process includes the following steps. First, Data Review Room (DRR) personnel physically monitor the launch process for specific data product start and stop events to occur. Next, after certain stop events occur (which may be hours or days following a stop event), DRR personnel log into the central data system (CDS), request a specific data product to be run, and specify the printer or plotter for the hard copy printout. The hard copy is either picked up or hand carried to the engineer (will calls). The responsible engineer then reviews the physical data product, analyzes the data for potential problems, and determines the health of the subsystem (analysis of large listings may take hours). The engineer then returns to the DRR to buy off the data product for which he / she is responsible (this can be 1 to 300 data products per subsystem).

The original goals of the S9002 automation project were (1) to automate the generation of greater than 80 percent of the data products for OMI S0007, with emphasis on hazardous gas; (2) to enable the display, to review, and to sign off those data products by responsible engineers from their desktop computers using the World Wide Web; and (3) to investigate the use of available commercial off-the-shelf products and / or rule-based technologies that could assist the responsible engineers with the analysis of the data products.

The S9002 database was modeled, designed, and implemented using a full-function RDBMS (Oracle 7) and a modern Web server. Code was written to automatically load the database from all available legacy system sources to include DRR Dbase IV, CDS formatted files, CDS transaction files, and CDS FD files. Listeners and agents were integrated into the database server to enable a transparent interface to all other S9002 subsystems, whether local or remote, and support many language interfaces.

An event monitor was designed and implemented using the Java language to monitor the occurrence of start and stop events and was interfaced to both the Shuttle Data Center (SDC) and S9002 databases. An application server module was also developed using the Java language, which communicates with the event monitor, SDC, the analysis module, and S9002 database to handle the scheduling and control of data product creation, transfer to the database server, and the triggering of data product analysis. In parallel, the programs that actually produce the data products (DAP's and CAP's) were moved from the CDS to the SDC and modified to enable production of electronic files. These programs also underwent significant coding modification to enforce standardization of inputs, options, and functionality. Tests where then performed to make sure the new S9002 application server module could successfully call and execute these SDC resident programs.

In another effort, an analysis module was being investigated and contrived. It was decided to create a rule-based application module that would perform the



Top-Level Menu Page for Administrators

same steps as an engineer when analyzing a large collection of hazardous gas sensor data. A complete set of rules was established for several of the largest data sets by interviewing the engineers and documenting their thought processes. These rules were then organized into a Java application class, and methods were written to enable reducing the analysis to a single page output that describes if there were any anomalies found. If there were anomalies, a brief explanation of each would be included along with violated parametrics.

Being developed in parallel with the other modules was the user interface. This module was scoped to run on platform-independent desktop computers, with the only requirement being that the platform support a commercially available Web browser. Two paths were taken in the development of the GUI. One implementation proposed the use of uploadable Java Applets for all menus and screens, which yielded compatibility problems with browsers, slow loading, and difficulties in coding and maintenance. The other implementation involved the use of the PL/SQL language for the dynamic creation of Hypertext Markup Language (HTML) sent to/from the client platform, which yielded a highly responsive, easy to code and use interface with dynamic screen sizing. While both solutions could eventually be made to work, the PL/SQL solution was chosen for implementation of the S9002 automation at this time. Results of the S9002 automation project to date have exceeded the original requirements.

As a result of this project, greater than 95 percent of data products for S0007 (orbiter launch) are run fully automatically and are typically available for viewing within 30 seconds after stop events occur. The S9002 database and application software supports all S9002 OMI's (approximately 5,300 data products). Engineers can run any data product at any time by specifying both start and stop times (will calls) and can create custom data products at will and execute them immediately. Several Space Transportation System flows can be run simultaneously without conflicts. The rule-based analysis of large volumes of data for hazardous gas has proven to be very efficient and has identified in near real time many interesting anomalies (gas leaks, power supply outages, etc.) hours before being discovered by the responsible engineers using manual methods. Responsible engineers now have a tool to monitor subsystem health, review discovered anomalies, and electronically sign off completed data products without leaving their desks.

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Participating Organizations: Dynacs Engineering Co., Inc. (W. Spiker, II; J.M. Dockendorf; and J. Zambrano), United Space Alliance (W.S. Bayles), and Boeing (D.J. Cox)

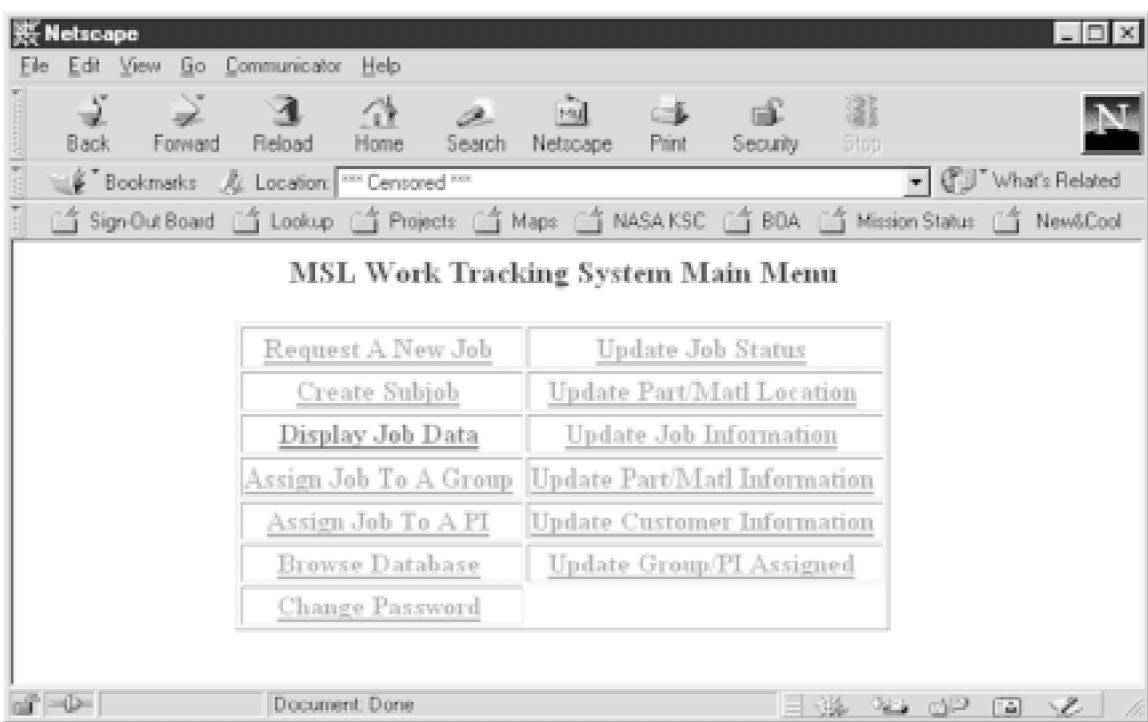
Web-Based Work Tracking Systems

The Logistics Operations Directorate's Materials Science Division (MSD) has a new software system running in real time on the World Wide Web. This system is named the Work Tracking System (WTS) and it demonstrates the integration of common Web browsers with a commercially available relational database management system to create a single, user-friendly means of controlling work flow.

The MSD laboratories were established during the Gemini era to provide quick laboratory support to vehicle and facility operations at KSC. The MSD was Government and contractor operated but was converted to a 100-percent Civil Service operation in 1968 so unbiased investigations could be provided.

Prior to this new application, each group in the MSD kept a separate report log containing unique fields, such as investigator name, date started, date completed, and report number. The WTS offers a single means of maintaining the report log and tracking the work flow, resulting in a much more efficient operation for both laboratory investigators and their customers. The WTS also aids the MSD in their effort to become ISO 9000 compliant.

The benefits and features of the WTS are many. The system is hardware and software independent on the server side – practically all server manufacturers and operating systems can run it. On the client side, practically all desktop computers, including



Administrators Page

Macintosh, PC, and UNIX work stations, can use WTS with a Web browser.

WTS offers a full-function, relational database management system (RDBMS). Features include referential integrity checking, security, transaction logging, and a distributed database. The RDBMS selected for the WTS implementation is Oracle because of its wide usage at KSC.

The Web pages are dynamically created in real time based on user inputs using Procedural Language / Structured Query Language (PL / SQL) that is stored in the database itself. Browser tables are also produced dynamically. The use of PL / SQL for WTS implementation results in fast system response time.

The WTS's current server configuration is a Sun Sparc II, running Solaris 2.5.1 (UNIX), Oracle Enterprise RDBMS, and Web server software. The client needs only a PC, Mac, or UNIX work station and a Web browser (such as Netscape or Internet Explorer) to access the system.

Similar systems were also developed and implemented at KSC, including the KSC Corrective and Preventive Action System tracking audit, nonconformity, and opportunity for improvement statuses. Other systems still in development include the KSC Centerwide Awards system that will track all NASA awards and the award budget. Other WTS demonstrable features include:

- Automatic e-mail to customers with status changes, such as job on hold, job complete
- Automatic notification to MSD personnel for new jobs and status updates
- Ad hoc reporting
- Security and access control with password and firewall
- Automatic file transfer
- Transaction logging
- Electronic signatures
- Add and display job documents including pictures and reports
- Job splitting
- Equipment calibration tracking
- Part / material tracking

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Participating Organizations: LO-G4-M (S. Murray) and Dynacs Engineering Co., Inc. (N. Tuttle and W. Spiker)

Atmospheric Science

The Atmospheric Sciences Technology program at the John F. Kennedy Space Center (KSC) addresses the impacts of weather on ground, launch, and landing processing with a view to increasing safety of personnel, protecting resources, and reducing lost work time by improving detection, analysis, and prediction of weather events and protection from weather events. Many of the weather impacts are of a specialized nature, differing from those felt by the public and even aircraft operations, and require studies and development that cross the lines of conventional scientific disciplines. Weather events focused upon by the program include lightning and cloud electrification, convective cloud growth, atmospheric surface and planetary boundary layer circulations and processes, wind shear effects, severe weather phenomena, rain, wind, and fog.

Hurricane Wind Sensor

The objective of this project is to develop a low-cost, high-speed wind sensor and a self-contained data acquisition system for in situ measurement of winds from hurricanes and tornadoes to 300 miles per hour. Scientists at the National Oceanic and Atmospheric Administration (NOAA) indicated a need for such a system and have formally requested KSC to undertake the development. When hurricane Andrew struck South Florida in 1992, there was no reliable land-based, maximum wind speed measurement. All known sensors in Andrew's path of maximum wind were destroyed, presumably in winds short of maxima. The controversy continues today with some scientists estimating Andrew's gusts at greater than 200 miles per hour. High wind speed information is needed at KSC to allow engineering assessment and recertification of facilities, ground support equipment, and flight hardware should an extreme wind event occur.

Figure 1. New-Generation Wind Sensor Incorporates Strain Gage Technology for Compact Design and High-Speed Performance

The high wind speed sensor (see figure 1) at KSC uses two different principles of physics to provide two independent measurements of wind speed: (1) the aerodynamic force imparted to a low-profile, rigidly mounted cylindrical rod and (2) the vibrating frequency of the rod as vortices are shed from the cylindrical surface. A common set of strain gages is used for both measurements. The force measurement is proportional to the square of the wind speed. Since it is a vector quantity, it can also be used to infer wind direction. The vortex shedding frequency is a scalar quantity and is linearly proportional to wind speed. The data system is battery operated, designed for unattended operation, and hermetically sealed to withstand driving rain and storm surge flooding that is typically associated with landfall hurricanes. The system will automatically acquire and store at least 72 hours of sustained and peak-wind information for poststorm event analysis.

A prototype data acquisition system was designed and fabricated. Three generations of prototype sensors were designed and tested with each showing

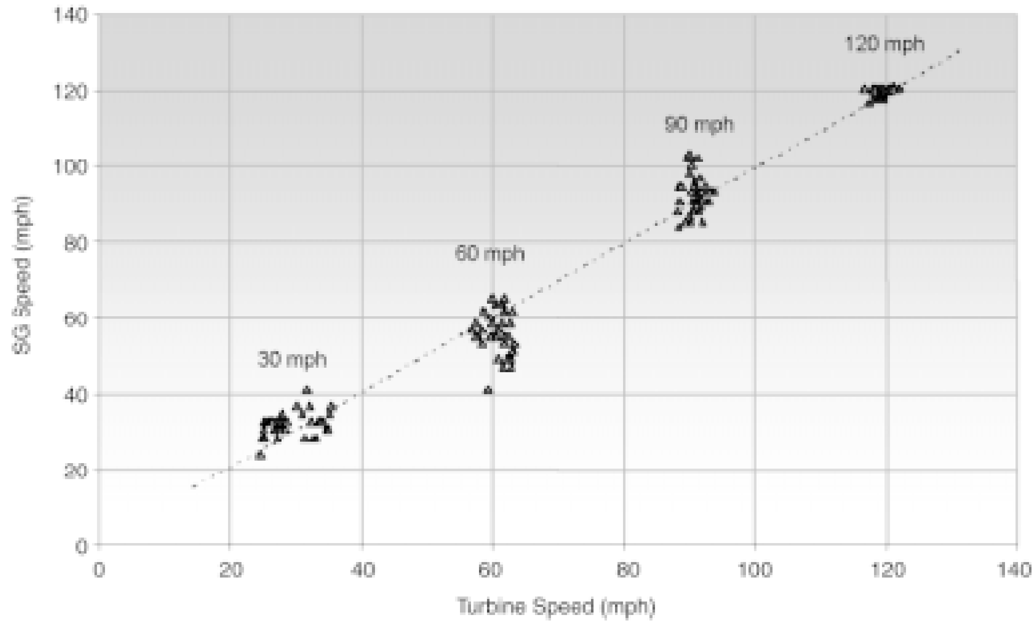

Figure 2. Raw Data Plot of Strain Gage (SG) Anemometer Versus Turbine Air Speed Sensor (Vehicle Test at the SLF)

significant improvement over its predecessor. The functional characteristics revealed during preliminary wind tunnel testing of the first design were used to refine the subsequent designs. The latter designs were tested to 120 miles per hour on a road vehicle at the Shuttle Landing Facility (SLF) (see figure 2). Wind speed values inferred from static strain (force) measurements agree well with those obtained from a co-located turbine air speed sensor. The frequency components of the sensor output, as related to the probe's mechanical resonance and vortex shedding vibration, have not been fully analyzed but preliminary findings show promise that independent wind speed measurements are extractable from the frequency spectra.

Key accomplishments:

- Designed and fabricated a prototype data acquisition system printed circuit board.
- Designed, fabricated, and laboratory tested three generations of prototype wind sensors.
- Proved that force measurement is a viable method of inferring wind speed and direction to at least 120 miles per hour (midcategory 3 hurricane).
- Initiated an investigation of vortex shedding frequency as a function of wind speed.

Key milestones:

- Deployment of sensor during 1999 Atlantic hurricane season.
- Final design and completion of sensor by October 1999.

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Participating Organization: Dynacs Engineering Co., Inc.

Single-Station Accurate Location of Lightning Strikes

The objective of this project is to design an accurate single-station lightning location system to aid in the detection of lightning strikes within the launch pad perimeter. This project is an upgrade to the lightning location system first conceived in 1997. Existing lightning location systems at KSC provide coverage of a wide area extending over a 30-mile radius but have an accuracy on the order of about 500 meters within the KSC area. These systems cannot be used to determine, for instance, whether a lightning strike occurred inside or outside the perimeter of the launch pads. Since electronic equipment can be damaged by the effects of nearby lightning strikes, the accurate knowledge of the striking point is important to determine which equipment or system needs to be retested following a lightning strike.

The fast-varying electric currents associated with lightning strikes generate large electric field variations. The electric field waveform propagates at the speed of light in a radial direction from the striking point. The sudden heating of the air caused by the large currents associated with the lightning discharge produces a sudden expansion of the air near the lightning channel. This results in a sonic wave (thunder) that initially, for the first few meters, propagates at a supersonic speed and later propagates at a sonic speed. For an observer located away from the striking point, the electric field waveform arrives earlier since it travels at a speed of 300,000,000 meters per second (m/s), while the sonic wave travels at about 320 m/s. The observer can determine the distance to the striking point by measuring the time between the arrival of the electric field waveform and the arrival of the sonic wave.

The improved lightning location system consists of an electric field sensor and five sonic (thunder) recorders. Four of these sonic sensors are located in the perimeter of a 1- or 2-meter-radius circle, 90 degrees apart from each other, with the electric field sensor placed in the center of the circle. The fifth sonic sensor is located 1 or 2 meters above the plane formed by the four sensors. Following a lightning strike, the sonic wave arrives at each sensor within milliseconds of each other, since the distance to the striking point is slightly different for each sonic sensor. Based on the differences in the time of arrival of the sonic wave at each sensor, a set of equations can be solved to determine the angle of arrival of the sonic waveform. The differences in the time of arrival can be precisely measured, to better than 10 microseconds, by performing real-time digital cross-correlations among the signals received by the five sensors. The distance to the lightning strike is determined by the time elapsed from the detection of the electric field to the detection of the thunder

signal, since the thunder propagates at a known speed of about 320 m / s.

Key accomplishments:

- Designed and prototyped the electric field sensor, the sonic sensors, and the microprocessor-based controller.
- Developed an algorithm to combine the information received from a network of sensors to determine the angle of arrival of the thunder signal.

Key milestones:

- Conduct field tests at the launch pads.
- Evaluate the performance of the system and refine the algorithms if needed.

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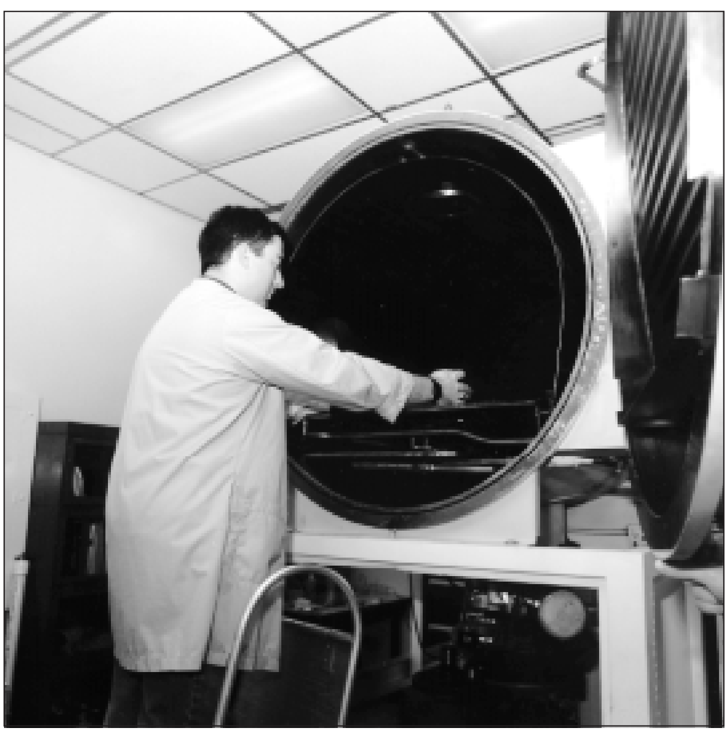
Participating Organization: Dynacs Engineering Co., Inc. (P.J. Medelius, J.D Taylor, and J.J. Henderson)

Materials Science

The Materials Science Technology program at the John F. Kennedy Space Center (KSC) supports advanced technologies directed toward improving launch site safety, operability, and maintainability. The program includes application materials engineering, materials testing, chemistry, and other science disciplines. The near-term program focuses on Shuttle ground processing improvement by providing materials and coatings that afford better corrosion control, materials with better hazardous systems compatibility, and improved testing methods and instrumentation. The long-term program will (1) investigate materials technology that can be used to develop new launch and processing facilities for future vehicles and payloads, (2) reduce the cost of maintenance, (3) provide higher safety and reliability, and (4) provide more environmentally friendly systems.

Study of Electrostatic Charging and Discharging of Materials in a Simulated Martian Environment

The Materials Science Laboratory has been studying and testing electrostatics of materials for the past 25 years. Electrostatics (or triboelectricity) is concerned with the tendency of materials to build up and hold a potentially dangerous static charge. Research efforts for electrostatic testing of materials under vacuum or in extraterrestrial environments do not exist. The goal of this project is to test the materials under vacuum that will be used for future Mars missions and to simulate Martian conditions to determine their triboelectric properties. Results from this testing will guide the selection of materials not only for Martian exploration but for other space exploration.



Vacuum Chamber

The potential issues regarding triboelectric properties of materials have become significant with the recent Pathfinder mission to Mars. The surface of Mars mainly consists of iron oxides and large amounts of very fine materials that are similar to talcum powder. Particles of this size pose special problems because they have increased mobility and can easily become attracted to oppositely charged surfaces from greater distances. The Martian environment is windy (30 meters per second at peak velocity) with periods of low temperatures and extremely dry conditions. This provides ideal conditions necessary to generate triboelectric charging.

The project was initiated in March 1998. A vacuum chamber 40 inches in diameter by 60 inches in length was purchased in April 1998 and is currently being equipped with controls to simulate the Martian environment. A robotic triboelectric tester is being designed to operate remotely in the vacuum chamber. A Martian regolith soil simulant was obtained from Johnson Space Center (JSC) for researching the possible electrostatic charging of Martian sands. The soil simulant is volcanic ash from the Pu’u Nene cinder cone on the island of Hawaii. Consequently, a prototype was designed and built for the soil simulant delivery system. The prototype will simulate the Martian atmospheric movement of soil to determine if there is electrostatic charge generation on the selected materials. The research efforts in the upcoming year will focus on the vacuum chamber, procuring the materials selected for the future Mars missions, and testing the simulant soil and materials at ambient conditions as well as in the simulated Martian environment.

Key accomplishments:

- Procured a vacuum chamber.
- Obtained and analyzed the Martian regolith soil simulant.
- Built and tested the first proof-of-concept prototype for a soil simulant delivery system.
- Initiated the design for the robotic triboelectric tester.
- Mars electrostatic discharge plan presented and accepted by JSC in situ resource utilization leads.
- Collaborated with Lewis Research Center, who is developing the methodology to remove dust from photovoltaic cell surfaces.

Key milestones:

- February 1999: Complete modifications to the vacuum chamber.
- September 1999: Complete the testing and calibration of the Martian Environmental Compatibility assessment electrometer attached to the Mars robotic mission for the Jet Propulsion Laboratory.
- October 1999: Determine the triboelectric characteristics of the simulant soil at ambient conditions and in the simulated Martian environment. Complete the fabrication and testing of the robotic triboelectric tester.
- September 2000: Determine the triboelectric characteristics of the selected materials under vacuum conditions and in the simulated Martian environment.
- May 2001: Submit the contribution to the electrostatics experiment package on the 2003 Mars robotic mission. Identify and evaluate methods to reduce charge buildup on Mars Rover mission vehicles.

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Investigation of Water Soluble Polyaniline as a Replacement for Chromate Coatings on Aluminum Alloys

Research has been ongoing for over 20 years at the KSC Materials Science Laboratory to find coating materials to protect launch site structures and equipment from the extremely corrosive conditions present at the launch complexes. The combination of proximity to the Atlantic Ocean and acidic combustion products from solid rocket boosters during launch results in corrosive stresses unique to KSC. In the mid-1980's, researchers at the Materials Science Laboratory became interested in polyanilines (PANI's) as protective coatings for metallic surfaces.

Several proprietary PANI-based coatings were tested at KSC as possible coatings for the protection of steel from corrosion. Exposure of PANI-coated steel panels at the KSC beach corrosion test site and evaluation by electrochemical impedance spectroscopy (EIS) led to the conclusion that the PANI-based coatings are not suitable as corrosion inhibitors of stainless steel.

The PANI-based coatings previously tested for the corrosion protection of steel were not water soluble. Water-soluble PANI's have been synthesized recently. Water solubility has favorable economic and environmental advantages in terms of ease of processing and of reduced toxicity. Interest in new protective coatings for aluminum alloys has been motivated by concern for improved protection and the environment. The availability of the water-soluble PANI coatings lead to the idea of testing them as possible replacements for chromate coatings on aluminum alloys.

In the present investigation, EIS was used to investigate the corrosion-inhibiting properties of a PANI-based coating on aluminum alloys under immersion in aerated 3.55-percent sodium chloride. The coating was prepared by mixing a water-soluble lignosulfonic acid doped polyaniline with a high solids methoxymethylated melamine resin in a 1:2 ratio. The alloys used were aluminum 2024, 6061, and 7075.

Corrosion potential and EIS measurements were gathered on the test specimens over a 1-week immersion period each. Nyquist as well as Bode plots of the data were obtained. The PANI-coated alloys showed large fluctuations in the corrosion potential during the first 24 hours of immersion that later subsided and approached a steadier change. The EIS spectra of the PANI-coated alloys were characterized by an impedance that is higher than the impedance of the bare alloy. Changes in the EIS spectra were similar for PANI-coated aluminum alloys 2024 and 7075. There was a decrease in the rate of corrosion of these alloys during the first 24 hours of immersion followed by an increase. The rate of corrosion of PANI-coated aluminum 6061 did not show the initial decrease. The rate of corrosion of bare aluminum 2024 decreased with immersion time. The low-frequency impedance (at 0.05 hertz), Z_{lf}, for the PANI-coated alloys decreased with immersion time. Visible signs of coating failure (in the form of blisters) developed on aluminum alloys 2024 and 7075.

Key accomplishments:

- Water-soluble polyaniline was synthesized.
- A coating using water-soluble polyaniline was formulated.
- Aluminum alloy panels with water-soluble polyaniline coating were prepared.
- EIS testing of polyaniline-coated aluminum alloy panels was conducted.

Key milestones:

- Conduct tests of polyaniline-coated aluminum alloys including exposure at the KSC beach corrosion test site and EIS measurements.
- Perform analysis of the metal substrate using metalography.

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Participating Organizations: Randolph-Macon Woman's College (Dr. L. Calle), LO-G4-M (L.G. MacDowell), and University of Arkansas at Little Rock (Dr. T. Viswanathan)

Qualified Materials Listings for Plastic Films and Adhesive Tapes

A need existed in 1990 at KSC for information that could readily be available to engineers who must make the choice of which plastic film to use for a specific application. Plastic films are commonly used to wrap flight hardware for ground processing, to package small components prior to delivery, or to provide limited barrier protection from minor (leaking) amounts of liquid rocket propellant. The adhesive tapes used to assemble and secure these plastic films must equally be readily available to the engineer. The need for qualified films and tapes was also driven by safety requirements that are unique to KSC (which include a reasonable resistance to flammability, a material that is minimal as an electrostatic generator, and total ignition resistance to hypergolic rocket propellants). While vendor literature could be used to determine the mechanical properties of a film or tape, there was no suitable industry data that could address the above safety concerns which would be acceptable to KSC.

In order to tailor the program for KSC, only those materials requested by KSC contractors were initially evaluated. Other materials that were submitted by other NASA centers or by vendors who wished to be included in the listings were evaluated when time and resources were available. An electronic database of test results was subsequently established from which the listings could be created. The test methods used to produce these test results were:

1. Flammability testing per NASA-STD-6001

2. Electrostatic testing per KSC / MMA-1985-79

3. Hypergolic ignition penetration testing per KSC / MTB-175-88

Each film or tape was subsequently categorized based on its ability to meet some or all safety requirements. This would enable the user to quickly access candidate materials once the operational needs are determined. A material must at least pass the flammability acceptance criteria before it can be included in the qualified listings. These listings are updated on a quarterly basis.

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Determination of Sodium in Colloidal Silica

Ludox AS-30, a product of DuPont, is a colloidal silica solution containing sodium that is used in many aspects of the orbiter's Thermal Protection Systems. Ludox is incorporated into thermal tile production and repair and flexible insulation blanket coatings and serves as the basis for adhesives. The amount of sodium present in the colloidal silica solution used for these purposes has a direct effect on the level of crystallinity observed due to the formation of cristobalite. The presence of cristobalite is detrimental to the performance of materials due to its tendency to exfoliate or flake. The Materials Science Division Test Branch has been involved with the development of a reliable and expedient method for determination of the level of sodium present in such silica colloids.

Several methods have been attempted in devising a quantitative analysis for sodium in silica colloids. Initially, ASTM Method C575-81, inductively coupled argon plasma (ICAP), and ion chromatography were used. None of these procedures gave reliable or reproducible results.

Following consultation with chemists at DuPont, a modified procedure using ICAP was developed. This method involves digestion of the colloidal dispersion using hydrofluoric acid and nitric acid. After addition of the acids, the samples are heated inside a CEM MDS 81D microwave until complete dissolution occurs. Presumably, acid digestion under these conditions has the ability to physically break the discrete uniform spheres of silica present in the colloid to release the sodium present. Digestion of aqueous samples (as received) was performed. The samples were also dried by oven heating and were digested using the same procedure. Verification of method reliability is accomplished by the addition of sodium spikes at varying concentrations.

The precision of the results obtained from the modified procedure is acceptable. However, the recovery of sodium added as a spike is consistently deficient. Before considering this procedure reliable, this anomaly should be understood. Literature research and additional testing are ongoing.

Key accomplishments and milestones:

- Literature research.
- Collaborated with DuPont.
- Continue testing the Ludox using different parameters for the digestion procedure.

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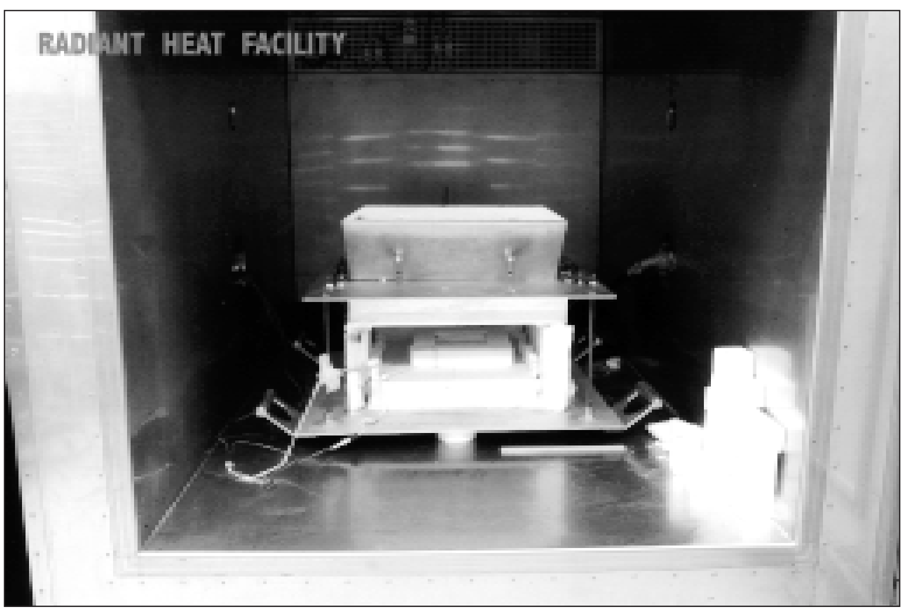
Participating Organizations: Boeing North American, Inc. (K. Marshall), DuPont (J. Ramsey), and LO-G3-C (D. Jackson and L. Wellington)

Inductively Coupled Argon Plasma Spectrometer
[Thermo Jarrell Ash Corporation (TJA 61E)]

Radiant Heating Facility

In order to perform testing on Thermal Protection System (TPS) materials, a facility is required to simulate a variety of surface-heating conditions. In the case of a vehicle reentering the Earth's atmosphere, the heating takes place under low atmospheric density conditions. Within the Materials Science Laboratory, there was a need to build a small chamber that could be used to simulate reentry heating on various types of TPS materials. It was decided to fabricate a small 18- by 18- by 8-inch chamber that could be placed inside an existing altitude chamber. With assistance from personnel at Langley Research Center and Ames Research Center, a small chamber was designed and fabricated. The chamber uses 24 infrared heating lamps to provide high surface heating to reach temperatures of over 2,200 degrees Fahrenheit. The chamber enclosure is fabricated partially from fused silica with a density of 24-pound-per-cubic-foot material provided by the Shuttle TPS facility. A power controller and separate temperature controller allow the user to select a ramp rate for the heating. Separate controls for the altitude chamber control the pressure in the radiant chamber during heating operations.



Key accomplishments:

- The chamber was fully activated and tested to over 2,000 degrees Fahrenheit.
- Extensive waterproofing burnout support was provided to the Shuttle upgrade project by looking at reducing the use of dimethylethoxysilane during rewaterproofing in the Orbiter Processing Facility.

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Participating Organizations: United Space Alliance (M. Martin) and Boeing North American, Inc. (M. Gordon)

X-33 Rocket System Fuel Tank Electrostatic Coating

The X-33 rocket program will demonstrate the key design and operational aspects of a single-stage-to-orbit reusable launch vehicle. The fuel and oxidizer tanks are covered by the outer vehicle shell. This design allows a small air space between these tanks and the outer shell, thus allowing a potential buildup of fuel and oxygen vapors in the space. Just prior to construction of the first vehicle, it was discovered that these tanks were covered with an insulating foam that had dangerous electrostatic properties. A search and testing sequence was then implemented. The final result was the selection of a lightweight electrostatic coating for all fuel and oxygen tanks that would neutralize the charge buildup in this confined space.

The coating is in an inaccessible location. The first coating material chosen was a clear, permanent, lightweight antistatic coating. However, further investigation revealed the coating had to survive an elevated temperature during reentry and survive as many as 25 launches without maintenance. These additional restraints proved hard to satisfy and resulted in the testing of many coatings by the Materials Science Laboratory before a satisfactory coating was found. The final coating consisted of small foam beads coated with silver and applied with an epoxy base. The testing proved the antistatic properties under the high temperatures and the number of cycles required.

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Analysis of Chloropel by Direct Pyrolysis/FTIR

Infrared spectroscopy is well recognized as a powerful tool in the characterization of a wide variety of materials including polymers, biological substances, and semiconductors. Unique infrared spectra act as a molecular fingerprint for materials. However, the information obtained using traditional Fourier Transform Infrared (FTIR) analysis may be limited when analyzing opaque, nonvolatile, and complex polymeric samples. For example, signal masking and interference may make it difficult to determine the composition of industrial polymer systems containing plasticizers, modifiers, and other additives.

These interferences may be overcome by combining infrared spectroscopy and pyrolysis, the thermal degradation of a material in an inert atmosphere. As the sample is pyrolyzed, the addition of thermal energy causes molecules to fragment according to the relative strength of bonds. A pyroprobe inserted into the FTIR interface places the quartz boat sample cell a few millimeters below the infrared beam. Materials evolved upon heating a sample pass through the infrared beam path and are detected.

The utility of direct pyrolysis/FTIR in elucidating the composition of a complex polymeric material was demonstrated. The degradation of chloropel, a polymeric fabric used in protective suits for hazardous operations, was investigated.

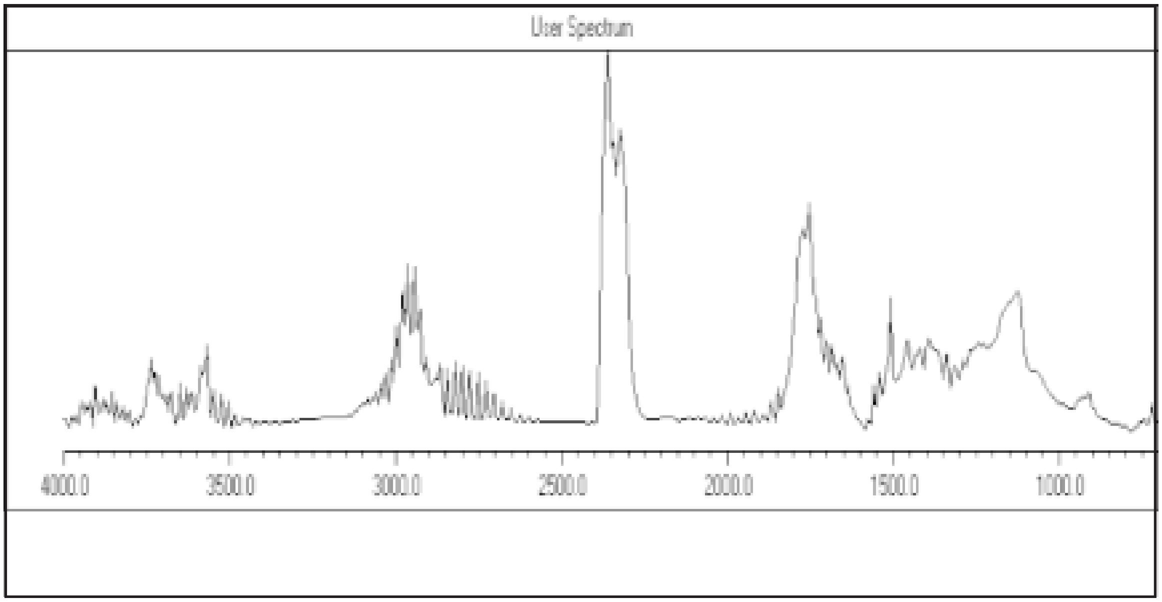
Thermogravimetric analysis was used to design an appropriate temperature profile. A heating schedule of controlled ramping at 20 degrees Celsius per minute (°C/min) and isothermal holds at 290, 445, 700, and 900 °C was used to isolate characteristic pyrolysates.

Infrared spectra obtained from the neat material using high-pressure anvil diamond cell and attenuated total reflectance yielded very similar spectra. Characteristics matching those of a polyester plasticizer typically found in polyvinyl chloride or chlorinated polymeric materials dominate the spectra.

Pyrolysis/FTIR provided additional information that facilitated the identification of other components in the chloropel material. The spectra of materials evolved at 250 °C (see the figure) showed the loss of hydrochloric acid (HCl) concurrently with the polyester plasticizer. This is evident in the distinctive HCl pattern of sharp peaks overlapping the hydrocarbon stretching between 2,560 and 3,060 wave numbers (cm^{-1}).

Spectra of another evolved species contained characteristics indicative of polyethylene. Residue remaining at temperatures above 1,000 °C indicates the presence of an inorganic additive.

In this study, components that were masked in traditional infrared analysis were identified



Polyester and HCl Pyrolysates

using pyrolysis/FTIR. Chloropel was found to contain a chlorinated polyethlyene polymer, polyester plasticizer, and inorganic additive such as a coloring agent.

Pyrolysis/FTIR was also used to study wire insulation that had significantly degraded and resulted in a failure. Pyrolysis/FTIR can provide valuable information into the chemical composition and degradation process of polymeric and composite materials.

Key accomplishments:

- Developed method parameters for pyrolysis/FTIR using a pyroprobe.
- Results indicate pyrolysis can be used to study the chemical composition and degradation process of polymeric materials.
- This technique will be used in failure investigations and polymeric research.

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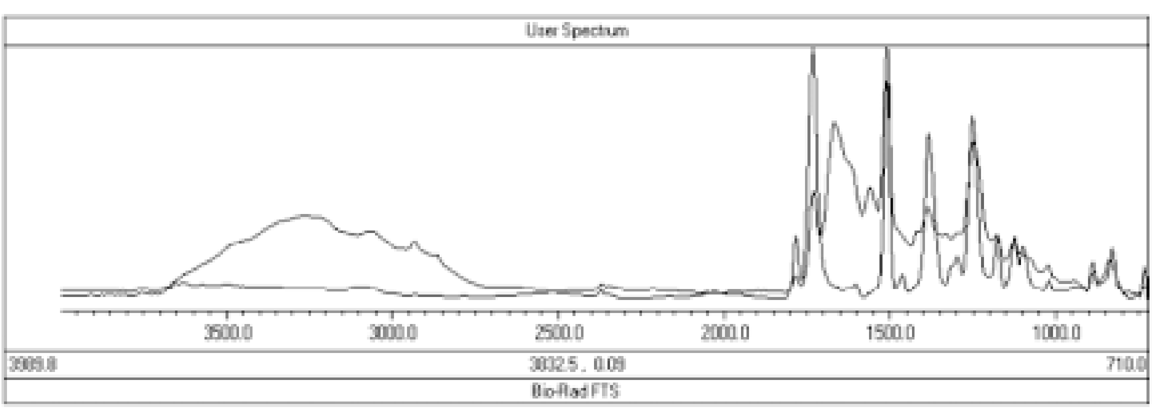
Participating Organization: C.M. Bradford, NASA Scholar (Georgia Institute of Technology and Spelman College)

Hydrolytic Degradation of Polyimide Wire Insulation

Polyimide wire insulation has long been the coating of choice because of its excellent electrical, mechanical, and chemical properties. The most common among the wire insulations used is the polyaromatic type that is routinely synthesized by the reaction of pyromellitic dianhydride (PMDA) and oxydianiline (ODA). Investigations carried out in the past several years showed that the polyimide class of wiring insulations was the subject of much debate. Wiring problems were encountered in the aircraft industry where it was found that the use of alkaline cleaners in contact with polyimide materials resulted in degradation of the coatings, thus resulting in fire hazards and electrical shorts.

Laboratory tests conducted at KSC revealed that polyimide wire coatings show degradation when exposed to hydrazine fuel. Hydrazine is used as a part of the propulsion systems and auxiliary power units (APU's). The APU's are used to power the hydraulic system of the Shuttle and other space vehicles. The hydrazine fuel has the property of acting as both an oxidizing agent and a reducing agent. It is also a weak base.

The laboratory tests conducted at KSC included reactions of polyimide with dinitrogen tetroxide, aqueous ammonia (30 percent), anhydrous ammonia (100 percent), and hydrazine fuel (100 percent). Fourier Transform Infrared (FTIR) analyses were performed on the wire test samples before and after exposure to the chemicals. Except for the dinitrogen tetroxide, a reaction product was observed on all other test specimens. The reaction product consisted of a yellow powder. Polyimides undergo hydrolytic degradation when



Comparison of Virgin and Exposed Polyimide (Ascending Order) exposed to alkaline solutions, and the yellow powder formed is characteristic of this reaction.

The postreaction FTIR analysis of the test specimens indicates the presence of two spectral bands not observed in the virgin polyimide material (see the figure). These bands occur at approximately 1,650 and 1,550 cm^{-1}. Literature references indicate the degradation products for this type of reaction are cyclic hydrazides and amines. The spectral bands observed therefore correspond to a carbonyl functional group (1,650 cm^{-1}) and the amine C-NH functionality (1,550 cm^{-1}).

Each of the alkaline solvents exposed to the polyimide insulations produced the same reaction product; however, the hydrazine fuel reacted most vigorously. The next series of tests included only the hydrazine, but the test specimens were exposed by direct- or drip-type application, total immersion, and vapor exposure. Results showed all the polyimide coatings reacted. After dissecting the wire insulation, it was observed that the hydrazine vapors even penetrated the second polytetrafluoroethylene (PTFE) layer and also the subsequent polyimide layers. The PTFE layer had a thickness of 0.001 inch (an increased thickness would serve as a better barrier).

The aircraft industry is thoroughly investigating this problem in light of recent accidents and because of the increased age of many of the aircraft still in service. As a result of degradation caused by many alkaline cleaners used in the aircraft industry, several manufactures of polyimide materials are now using more layers of PTFE and are also searching for new polymer materials that can serve as chemical barriers (resistance to alkaline).

Key accomplishments:

- Data confirmed that exposure to hydrazine (and other alkaline chemicals) results in the degradation of polyimide insulation.
- The volume of exposure and performance of insulation should be addressed when investigating possible polyimide insulation failures.

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Participating Organizations: Wiltech Corporation and Langley Research Center

Epoxy Bonding Agents

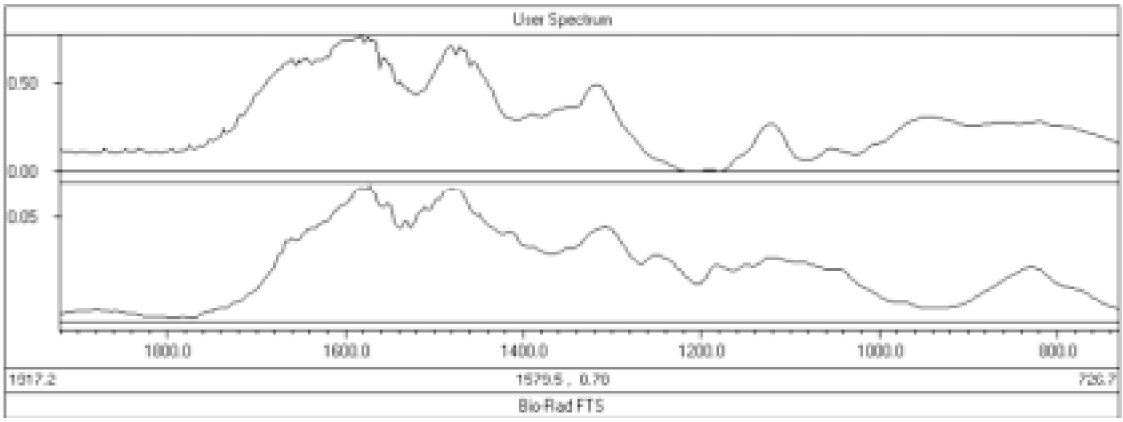
Epoxy resins are characteristically strong and resistant to heat, water, and organic solvents. It is for these reasons that epoxy resins are used in diverse applications, one of which is attaching strain gages to stainless-steel bolts. Since epoxy resins are capable of crosslinking without the emission of volatile components, they are particularly suited to application on impervious materials such as stainless steel, aluminum, and glass, which can then be bonded with little or no pressure.

In an investigation involving a strain gage attached to a stainless-steel bolt, erratic voltage readings were observed. Visual inspection revealed the presence of red liquid pockets in the epoxy material. The red liquid was analyzed by Fourier Transform Infrared (FTIR) spectroscopy for molecular composition and was identified as an uncured epoxy material. After removal of the epoxy from the top of the strain gage, more uncured liquid was found next to the strain gage circuit. Further analysis determined that the cure of the epoxy material was inhibited by moisture absorption. Moisture increases the pH (more alkaline) of the epoxy's curing agent. The higher pH can have corrosive effects on copper components, which along with electrical supporting data suggested the failure mode of the strain gage.

Although there are several types of epoxy bonding agents available, this particular type is a two-part system in which an amine is used to induce the crosslinking/cure process. Amines are basic materials (pH is greater than 7). The mixing instructions for the epoxy state that, after the amine curing agent is added, the epoxy should be mixed for 5 minutes and allowed an additional 5 minutes before applying the epoxy. Simulations of this application process in the laboratory still indicated the presence of uncured epoxy (confirmed by FTIR analysis).

To evaluate the root cause of the curing problem and to identify any interfering components, several tests were performed to assess the application process. Contamination from the flux (rosin) material used in soldering was found to induce no adverse effects (acidic pH was approximately 6). However, as expected, when minute quantities of water were added, an inhibitory effect on the epoxy cure was observed.

The application of the epoxy appeared to be most successful at room temperature when the epoxy was mixed for 5 minutes and then applied after an additional 10 to 15 minutes (may vary with the temperature and humidity of the room). The additional time allows for the crosslinking process necessary to obtain a full cure and decreases the interference of the moisture. The addi-



Note: A similar chemical pattern is exhibited in the fingerprint region of each infrared spectrum.

Comparison of Liquid Amine Curing Agent and Reddish Liquid Contaminant (Descending Order)

tional time will ensure a good cure and still be within the shelf life stipulated by the manufacturer. Another recommendation for the application process is to use a nitrogen purge.

Key accomplishments:

- Results suggested a failure mode for the strain gage.
- Recommendation for improvements in the application of epoxy used for strain gages.

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Participating Organization: LO-G4-E (J.A. Bayliss)

Cryogenic Insulation Systems for Soft Vacuum

A cryogenic insulation system for an operation under a soft vacuum was developed at the KSC Cryogenics Test Laboratory in 1998. Conventional insulation materials for cryogenic applications can be divided into three levels of thermal performance, in terms of apparent thermal conductivity (k-value in mW/m-K). System k-values below 0.1 can be achieved for multilayer insulation operating at a cold vacuum pressure (CVP) below $1x10^{-4}$ torr. For fiberglass or powder operating at a CVP below $1x10^{-3}$ torr, k-values of about 2 are obtained. For foam and other materials at ambient pressure, k-values around 30 are typical. New industry and aerospace applications require a versatile, robust, low-cost thermal insulation with an overall performance in the moderate range. The target for the new composite insulation system is a k-value below 3 mW/m-K at a soft vacuum level (from 1 to 10 torr) and boundary temperatures of approximately 77 and 293 kelvin. Many combinations of radiation shields, spacers, and composite materials were tested from high vacuum to ambient pressure using cryostat boiloff methods. System design considerations included installation, outgassing, evacuation, compression, and end effects. As shown in the figure, significant improvement over conventional systems in the soft vacuum range was demonstrated. The new layered composite insulation system was also shown to provide key benefits for high-vacuum applications as well. Optimization of the insulation system for specific applications (such as liquid oxygen storage on Mars, liquid nitrogen conduit for superconducting power lines, advanced launch vehicles, and Shuttle upgrades) is planned for 1999.

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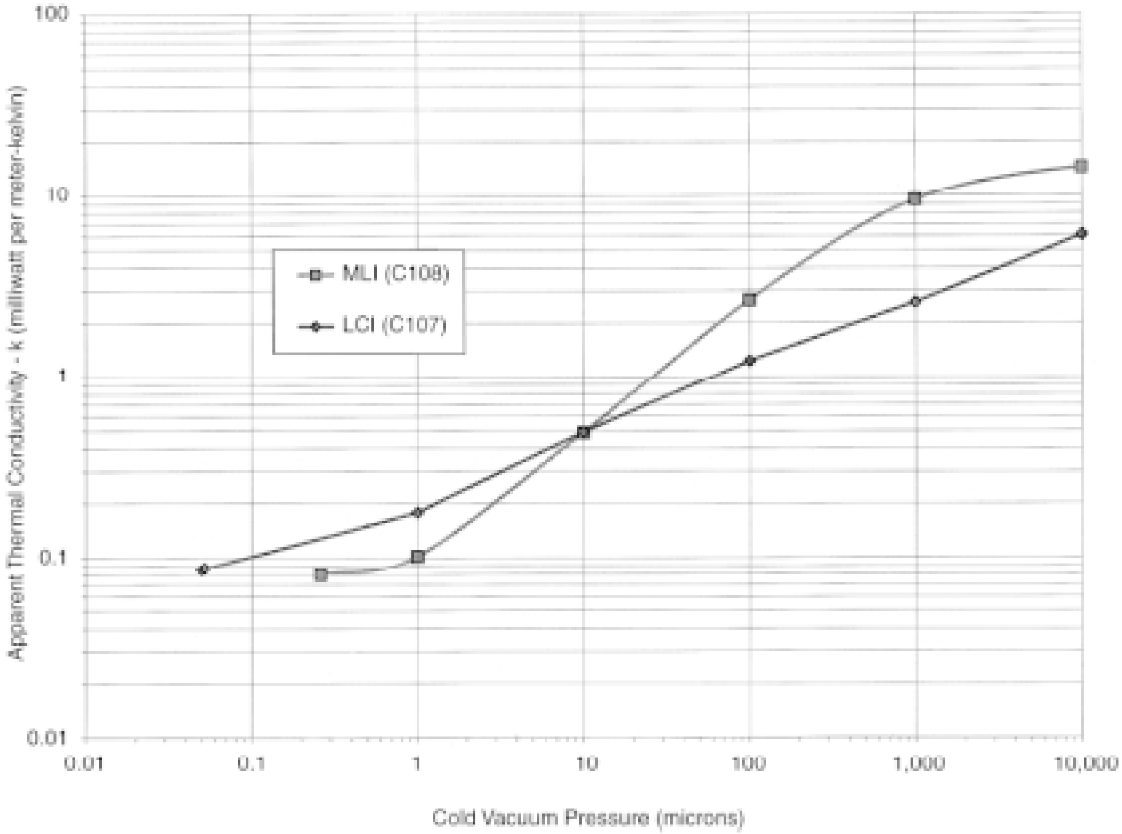
Participating Organization: Dynacs Engineering Co., Inc. (S. Augustynowicz)



Thermal Conductivity as a Function of Cold Vacuum Pressure
[Comparison of Layered Composite Insulation (LCI) and Multilayer Insulation (MLI)]

Permanent Antistatic SCAPE Suit Coating

A research grant was given to Belland Corporation of Andover, Maine, to develop an easy-to-apply, permanent, clear antistatic coating. This coating is to be applied to the Self-Contained Atmospheric Protective Ensemble (SCAPE) used during toxic fueling operations at KSC. The evaluation testing is currently being done by the electrostatics engineers of the Materials Science Division (MSD).

The SCAPE suits presently used for worker protection during Shuttle fueling operations are electrostatically capable of generating voltages in excess of 20,000 volts. This is a high voltage capable of producing catastrophic electrostatic discharges. This potential was controlled in the past with an application of topical antistatic spray. This solution has several disadvantages. It is only temporary since the solution must be applied to the suit every hour during work. There is an ever-present danger if the antistatic material is rubbed off during the work and there is some concern about exposure to the spray during application. If a worker becomes injured, the ability of the rescue team to remove the injured worker is difficult due to the slick nature of the spray. The potential hazard of not using this spray was clearly demonstrated in a previous incident where a small fuel fire was ignited during Orbiter Processing Facility operations in the Orbital Maneuvering Subsystem pods. An electrostatic discharge from the uncoated suit material was the most probable cause of the fire.

Test results of one promising version of the coating reduced the maximum suit voltage generation from above 20,000 volts to below 1,000 volts. At this time, the testing is concentrating on the adhesive properties and the chemical compatibility with a variety of fuels and chemicals. These test results are encouraging, and the coating seems to improve the suit protection for certain fuels.

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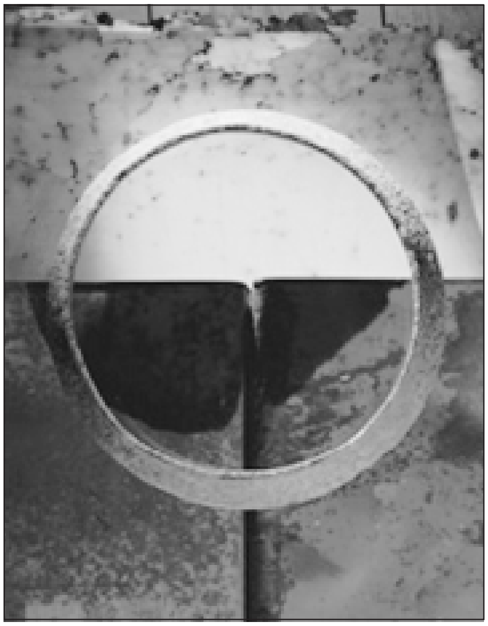

Nondestructive Evaluation

The Nondestructive Evaluation (NDE) Technology program at the John F. Kennedy Space Center (KSC) includes the development of inspection and verification instruments and techniques that can provide information (external or internal) to hardware and component structures in a nonintrusive manner. The technology includes, but is not limited to, laser, infrared, microwave, acoustic, structured light, other sensing techniques, and computer and software systems needed to support the inspection tools and methods.

The present effort in this discipline is being directed toward reducing Shuttle processing costs using these technologies. The long-term effort of the program is to develop cost-effective NDE techniques for inspecting and verifying space vehicles and their components during manufacture and to continue validating those items during assembly/launch and on-orbit or during space flight.

Condition Monitoring and Fault Identification in Rotating Machinery (CONFIRM)

Loading of the Space Shuttle external tank with liquid oxygen is accomplished via a pump/motor/bearing assembly located at the northwest corner of Launch Complex 39. Since the assemblage is vital to the success of any mission, it is continuously monitored to detect, identify, and assess its condition and take appropriate actions to minimize the impact on launch. Condition or health monitoring technologies that are being considered for use fall into two major categories: Mechanical Vibration Signature Analysis (MVSA) and Motor Current Signature Analysis (MCSA). Also, the Acoustic Emission (AE) technique and a Lube-Oil Analysis (LOA) will be used as early warning tools for predicting impending failures. Mechanical, electrical, and flow-induced problems will be addressed in this multiyear research program.

The present effort is directed toward the installation of a pump/motor/bearing assemblage at the Launch Equipment Test Facility (LETF) to simulate Launch Complex 39. This setup will provide a test bed for research and development, testing of variable frequency drives, and hands-on training for launch pad personnel. The assemblage will serve as a platform for the evaluation of newer online condition/health monitoring technologies. Such online machinery monitoring will lead to improvements in operational efficiency, eliminate shutdowns, reduce maintenance costs, and prevent catastrophic failures. Early detection and correction of impending failures will significantly improve reliability while enhancing safety.

Key accomplishments:

- 1998: Implemented the liquid oxygen pump assemblage at the LETF. Validated the use of AE, MVSA, and MCSA techniques in identifying rotating machinery defects.

Key milestones:

- 1999: Assess condition monitoring technologies and variable frequency drives on the 300-horsepower pump assemblage. Additionally, validate the MCSA technique and coordinate with MVSA methods.

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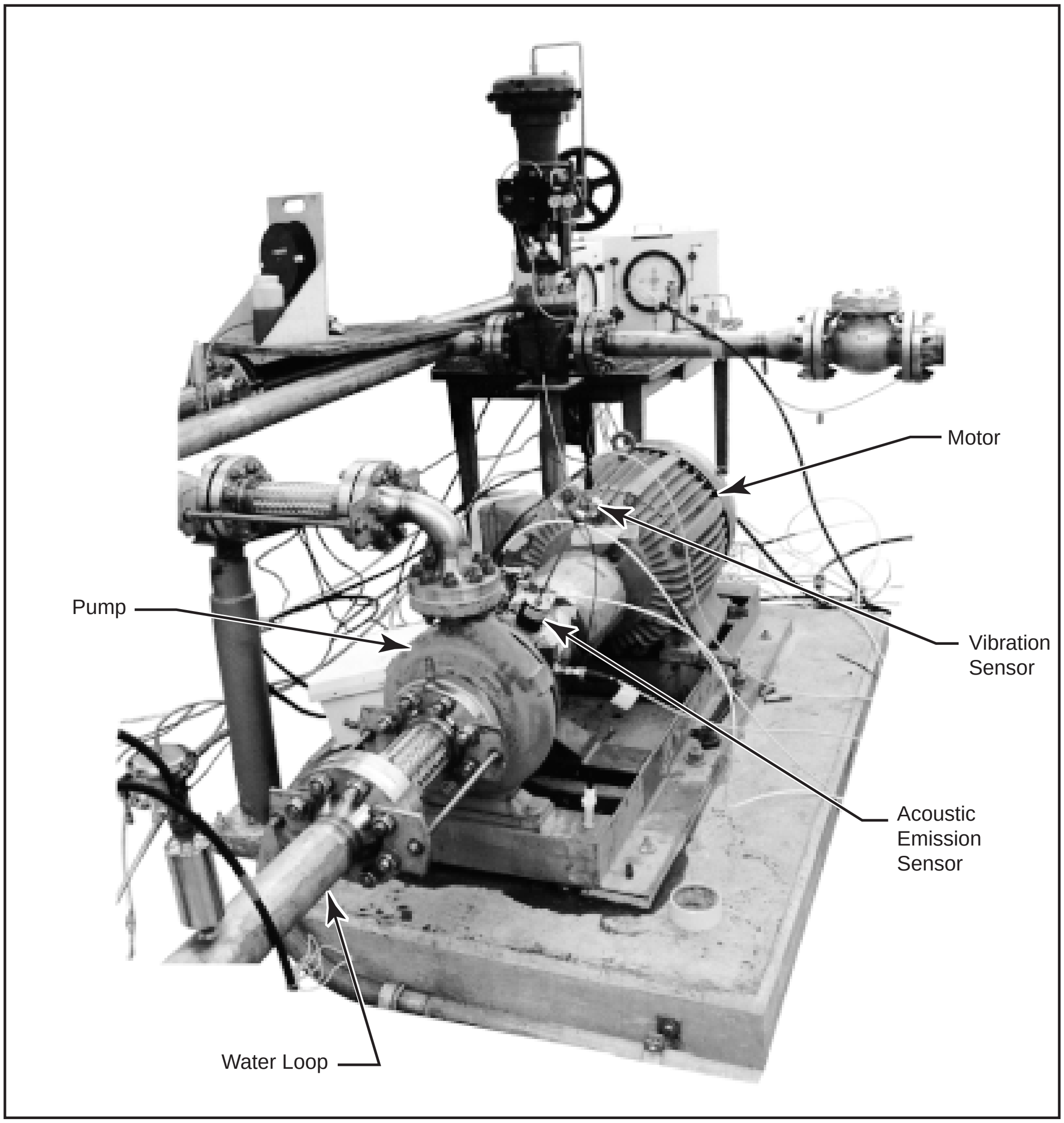
Participating Organizations: Dynacs Engineering Co., Inc. (R.N. Margasahayam and M.J. Ynclan) and Information Dynamics, Inc. (L. Albright and O. Varosi)



Simulated LETF Water Pump Motor Facility

Evolved Expendable Launch Vehicle (EELV) Hydrogen Testing

This report describes the equipment, procedures, and qualification testing to be used to evaluate the mixing of hydrogen and oxygen in the simulated plume of the EELV RS-68 engine. The EELV engine is similar to the Shuttle engine, which uses hydrogen as the fuel and oxygen as the oxidizer. These engines start the flow of hydrogen before oxygen is added during the launch sequence, and the oxygen flow stops before hydrogen upon shut down. Both of these situations leave hydrogen, which must be burned off before the area is safe. Therefore, this excess hydrogen must be burned in a manner that precludes detonation. The procedure is to entrain oxygen from air in hydrogen to provide a combustible mixture, then to ignite this mixture so a controlled burn occurs.

The primary objective of this test program is to qualify a combustion ignition system that would burn hydrogen from an aborted launch. To simulate the firing of the EELV engine, nitrogen will be released into a 1/7-scale flame trench. These releases will last 0.7 second and will include hydrogen combustion as part of the simulation. This project has three phases: Phase 1 requires analysis of ambient oxygen in nitrogen, Phase 2 requires analysis of hydrogen added to ambient oxygen in nitrogen, and Phase 3 requires analysis of hydrogen burning with ambient oxygen in nitrogen. To make these measurements, grab-samples of the atmosphere will be collected just before release, during release, and just after release. The sampler (see figure 1) is constructed of sections of tubing linked between valves so the flow rate of the sample matches the total tubing length. Therefore, each section represents a time history of the concentration of the gases as they pass the sample inlet. The contents of the sample tubes will be analyzed by gas chromatography, a method

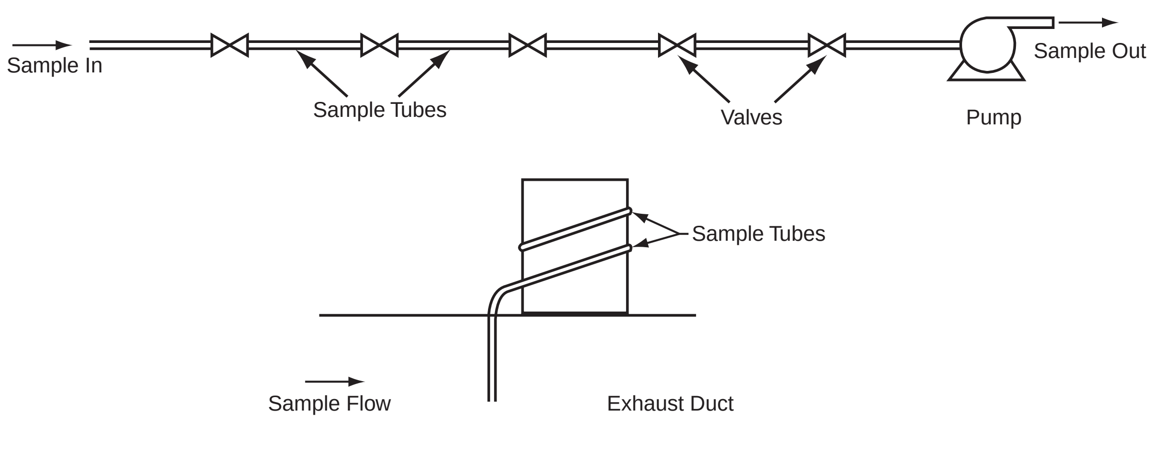


Figure 1. Sampling Setup for One Point of Six Sample Points Across the Exhaust Duct

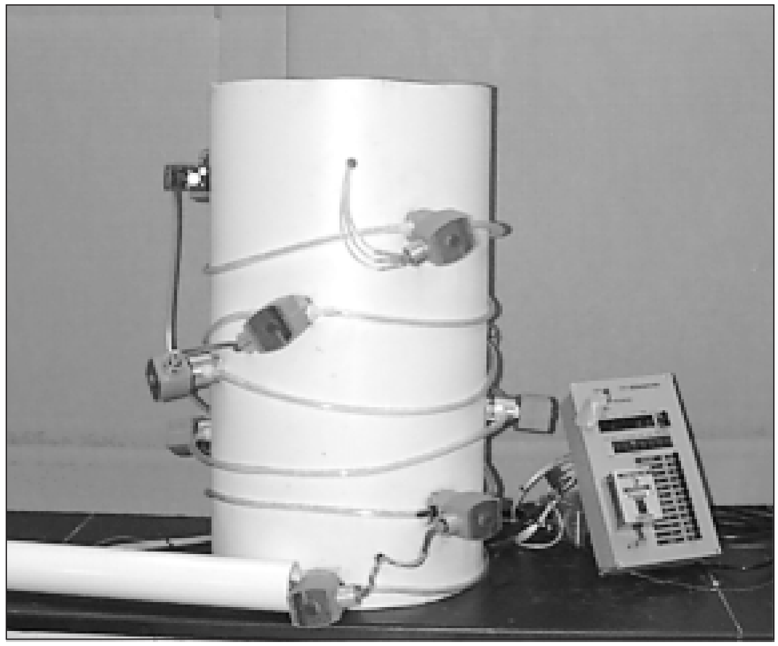


Figure 2. Sampling System With EELV Test Simulation Equipment

that can measure the concentration of each gas at 0.2 percent.

The sampling system seen in figure 2 shows the sample lines, valves, and sequencer that times the opening and closing of the valves which separate the samples. The procedure to be used will clamp the sample tubing on either side of the valves to isolate the sample. This will allow a fast turnaround of the sampling system, since it will only require replacing the sample tubes with new precut tubing. The samples in the tubes can be analyzed by a gas chromatograph independently of the EELV testing.

Key accomplishments:

- Developed a method to measure the concentration profile as a function of time during EELV testing.
- Designed and produced six units to capture the test samples.
- Developed the sample introduction system for the gas chromatograph.
- Demonstrated that the method could measure the concentration of oxygen and hydrogen to less than 1 percent in nitrogen.

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Participating Organization: Dynacs Engineering Co., Inc. (C.F. Parrish, C.J. Schwindt, T.R. Hodge, and P.H. Gamble)

Thermography for Nondestructive Evaluation and Laser Shearography

NASA, United Space Alliance, Boeing North American, Inc., and Dynacs Engineering Co., Inc., engineers and scientists performed shearography and thermography inspection of Atlantis (OV-104) payload bay doors at Palmdale, California. The payload bay door structure is composed mostly of graphite-epoxy honeycomb and laminate. No existing inspection can adequately inspect this composite structure. Two new techniques, shearography and thermography, were used to inspect about 70 percent of the structure shell in 7 working days (one shift). Both techniques worked well regarding the rate of inspection and sensitivity. Several defects were detected, most resulting from maintenance-induced damage. All suspect defects were corroborated with ultrasonic inspection before defining any repair.

These results are a continuing effort at KSC to develop a reliable inspection method for composites. Two other vehicles, Discovery (OV-103) and Endeavour (OV-105), have had similar inspections with good results. Boeing has written specifications certifying these techniques for use on the Shuttle.

Future actions include developing the sensitivity and accuracy of each technique in various applications, developing operator procedures and certification, and extending the applications to other areas including the external tank and solid rocket booster thermal protection system and leak visualization.

Key accomplishments:

- 1996: Discovery payload bay door inspection.
- 1997: Endeavour payload bay door inspections and shearography and thermography specifications published.
- 1998: Revised shearography and thermography specifications to include a general procedure. Atlantis payload bay door inspection.

Key milestone:

- 1999: Probability of detection curves for the most common composites for the orbiter.

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Participating Organizations: United Space Alliance (K.R. Wagner), Boeing North American, Inc. (A.M. Koshti), and Dynacs Engineering Co., Inc. (J. Donahue)

Process/Industrial Engineering

NASA's Kennedy Space Center (KSC) is developing as a world-class spaceport technology center. Process/industrial engineering technologies are integral spaceport technologies. From a process or industrial engineering (IE) perspective, the facilities used for flight hardware processing at KSC are NASA's premier factories. The products of these factories are among the most spectacular products in the world – safe, successful Shuttle and expendable vehicle launches carrying tremendous payloads. The factory is also the traditional domain of the discipline of IE. IE is different in many ways from other engineering disciplines because it is devoted to process design, management, and improvement, rather than product design. IE also emphasizes the relationships of workers with systems and processes. Spaceport processes have many unique aspects that require development of innovative IE technologies, such as complex and risky depot-level maintenance processes, high-performance system test and checkout procedures, and low-volume manufacturing processes.

Process/industrial engineering technologies address the generic challenge of "doing more with less." IE is typically used to optimize the operational phase of a program. IE technologies introduced early in the program life cycle (during concept, design, and development phases) generally deliver outstanding results. The Space Shuttle is NASA's first major program with a long-term operational phase, and many current and potential future programs (i.e., the International Space Station, X-vehicles, and human space flight to Mars) also are projected to have lengthy operational phases. Therefore, the strategic importance of process/industrial engineering research and technology development to NASA is rapidly increasing.

Technologies include methods, tools, techniques, and processes as well as hardware and software. Most IE technologies evolved from the need to improve shop floor productivity. IE technologies are now successfully used to design and enhance every type of process in Government agencies, production industries, service industries, and academia. Therefore, spaceport process/industrial engineering technologies can be effectively transferred to a variety of additional organizations.

The growing need to do things better, faster, cheaper, and safer has improved the potential value of process/industrial engineering technologies. The articles in this section are divided into five interrelated areas of process/industrial engineering: Management Support Systems, Human Factors Engineering, Work Methods and Measurement, General IE, and Process Modeling and Analysis. Your feedback to the contacts listed in these articles is appreciated.

Management Support Systems: Goal Performance Evaluation System

In 1993, Congress passed the Government Performance and Results Act. A key requirement of this legislation is that all Federal agencies develop strategic plans. A 1997 Congressional report graded the strategic plans that were submitted. The report noted that agencies failed to explain how their goals linked to their day-to-day operations and to each individual employee's performance plans/appraisals.

NASA's Strategic Plan states that each NASA Center Implementation Plan should be "…the communication tool used to enable the Center's customers to see that their requirements are being addressed and to ensure that employees understand their contribution to the highest level strategies and objectives of NASA. The final linkage is made through each individual's performance plan appraisal" (from NASA Strategic Management Handbook, October 1996). The Goal Performance Evaluation System (GPES) was developed to make this "final linkage" to bring the NASA Center Implementation Plan to the employee and to encourage strategic linking and implementation at every level in the organization.

The potential for this research was to address the execution of an agency's strategic plan. Ultimately, the employees of an organization are responsible for the action planning, task execution, and accomplishments of their organization. However, few tools exist that accommodate these objectives or that focus on the specific needs of a Federal agency. The GPES was developed to aid NASA in implementing the Vision and Strategic Objectives outlined in the Agency plan.

The GPES was developed as a Web-based strategic planning tool used for planning, managing, and evaluating employee contributions to NASA Center and NASA-wide strategic objectives. Each employee performance plan contains objectives and strategies derived from directorate-level goals and objectives. All directorate objectives are electronically available in the GPES, including the links to higher level goals. The supervisor defines employee performance by selecting objectives and strategies from a "drop down" menu. Since the supervisor no longer has to write job elements and performance requirements for every employee, the supervisor can focus on individual goals. Employees can enter their achievements and track them throughout the year. Status reports are available at the directorate and Center levels.

The GPES tracks the links from directorate mission objectives and mission strategies to Agency and Center strategies and links from individual performance objectives to directorate objectives and strategies. Metrics are maintained for status of performance plans, links to objectives and strategies, system utilization, performance indicators, and the number of World Wide Web accesses to related promotional banners of interest to employees.

The GPES is fully operational at KSC and is being used for the 1998/99 employee appraisal period. The GPES was presented and well received by all NASA Center Directors and the NASA Administrator and is currently being implemented at Johnson Space Center (JSC). The GPES software continues to be enhanced with additional features, such as:

- Supervisor safety and health metrics (via an automated point system)
- Supervisor 360 assessment feature
- Online performance award / evaluation
- Online collection of community outreach activities for employees

Key accomplishments:

- 1998: Successfully developed and implemented the Web-based GPES for all Civil Servants at KSC and implemented the GPES for all Civil Servants at JSC.

Key milestone:

- 1999: Continue deployment of the GPES to other Manned Space Flight Centers.

GPES Command Center Menu:

- **Automates the employee performance appraisal process, from planning through appraisal.**
- **Provides a direct link between overall organization/directorate strategic plans and employee performance.**
- **Integrates business goals and objectives with daily work processes.**
- **Provides centralized data for summary evaluation of organizational objectives.**
- **Aligns resources toward successful achievement of overall goals/mission.**
- **Affects behavior toward strategic thinking and implementation.**

Beneficial software design attributes include:

- **Easy customization.**
- **Intuitive graphical user interface.**
- **Web-based or intranet application.**
- **Integrated application using off-the-shelf tools.**

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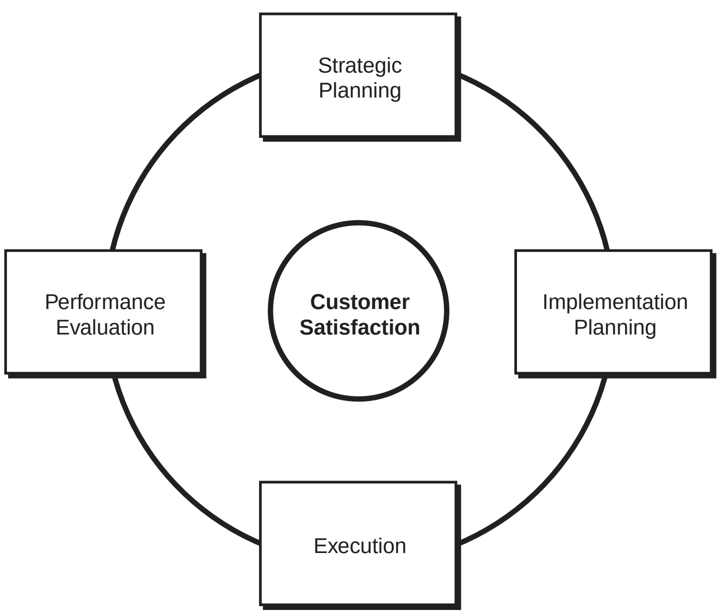
Management Support Systems: Organizational Change Models for Strategic Management

Government organizations, as is the case with private organizations, are being required to change their present operations to align with the ever-changing environment. Often this change need leads to a large-scale transformation including a change in mission or core business. With the change in mission, the organization must also change the manner in which it completes its core business (i.e., the processes, tools, and people). One of the first steps in achieving successful change and transformation is to create a vision of the future. Strategic management has been offered as a method to drive organizational change. Strategic management is a continuous process aimed at aligning everyday actions with the long-term direction of the organization based on the needs of the customer. An organization can use strategic management to achieve a set of strategic thinking outcomes and produce a set of products to move the organization forward. The objective of this research is to understand and demonstrate the use of the strategic management process to drive large-scale transformation.



Strategic Management Process

As shown in the figure, the process of strategic management includes the functions of strategic planning, implementation planning, execution, and performance evaluation. KSC used this process to develop a set of products: a strategic direction, project plans, an initial set of performance measures, strategic results, and lessons learned.

Strategic planning is a group process by which the organization defines or refines the organization's mission (core business statement), vision (ideal future state), goals, and objectives. The process involves understanding both the internal and external environments (e.g., strengths, weaknesses, opportunities, threats, etc.). The output of strategic planning is an integrated set of goals, objectives, strategies, and projects to improve performance.

For KSC, the strategic planning process focused on defining a strategic direction with products of a future state, core business, and strategic roadmap. The Center Director shared the message via a KSC-wide rollout process he presented at an all-hands meeting and then visited with each directorate at KSC. The Strategic Plan became real through the implementation planning process.

Implementation planning is the process by which the organization develops specific strategies or actions to implement the strategic direction and defines the specific measures of performance that will determine the progress of the planned actions. Implementation planning provides the detailed performance planning and proposed resource allocation to implement the Strategic Plan. An organization uses the implementation plan to guide day-to-day behavior or execution. Execution is the carrying out of the implementation plan.

Performance evaluation is the process by which the organization understands the impacts of the projects on the goals and objectives. The use of performance measurement and evaluation creates tangible results that can be studied to produce lessons learned and recommendations on how to improve the organization and adjust the Strategic Plan.

The customer satisfaction process is the foundation for the strategic management process by providing information and knowledge about how KSC can meet and exceed customer needs.

Key accomplishments:

- 1997: Conducted an internal and external research study on the success factors for strategic management.
- 1998: Conducted a cycle of strategic management with KSC.

Key milestones:

- 1999: Refinement of a set of processes and integrated schedule for strategic management. Development of a best-practices model for deploying strategic management.

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Participating Organization: University of Central Florida (T. Kotnour, Ph.D.)

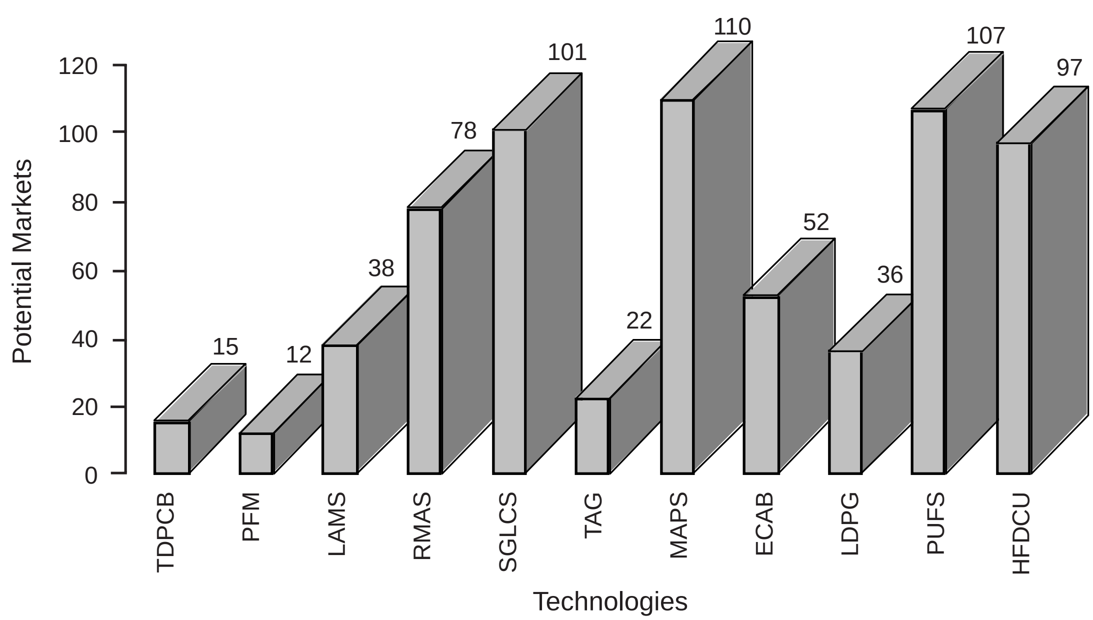
Management Support Systems: Methodology To Harvest Intellectual Property at KSC

Information and data obtained through problemsolving and decisionmaking can be converted into intellectual capital. The need to acquire intellectual capital created the knowledge management movement, which aims to develop new practices and tools to capture knowledge. Knowledge management in general tries to organize and make available important know-how, wherever and whenever it is needed. This includes processes, procedures, patents, reference works, formulas, "best practices," forecasts, and fixes. One kind of knowledge management project attempts to manage knowledge assets from a financial perspective. KSC's focus on this project is on intellectual capital and harvesting little-used patents and intellectual assets. As the Center responsible for preparing and launching space missions, KSC is placing increasing emphasis on its technology development program. KSC maintains a vigorous applied research program in support of Shuttle launch activities. Ground support systems, launch and processing facilities, and environmental protection all require continued attention for KSC to remain the Nation's premier state-of-the-art spaceport. Focusing predominantly on applied research prompted KSC to develop new technologies and expertise directly applicable to commercial products and manufacturing needs.

Technology commercialization is a primary goal of NASA's Technology Transfer Program. Patent and copyright licensings are key mechanisms to accomplish this goal. In order for NASA to continue to increase the number of successfully commercialized technologies, NASA must identify commercial applications for its new technology and effectively seek out commercialization partners.

Key accomplishments:

- 1997 and 1998: Alternative commercial applications were identified for 11 KSC-developed technologies. Four technologies were analyzed in the last half of 1997 and seven in the first three-quarters of 1998. These advanced technology development projects have been proposed, are currently under development at KSC, have been completely developed, or have already received intellectual property protection. Potential markets associated with the new applications were investigated, which provided profiles of key companies that may be interested in partnering with NASA. The current state of similar or



Potential Markets

applicable commercially available technology and potential for dual-use development with industry was investigated. Assistance in identifying and characterizing qualified leads associated with commercializing NASA technologies was provided. Companies were categorized primarily on the basis of capabilities, interests, and areas of expertise. A comprehensive report containing a synopsis of each advanced technology project as well as a review of possible partners and applicable commercially available technologies was prepared. KSC was provided with 668 leads for potential commercialization partners and 110 new potential uses for the following technologies (the figures show detailed information of the new uses and potential commercialization partners):

- Environmentally Controlled Abrasive Blastsuit (ECAB)
- Hydrogen Fire Detector Calibration Unit (HFDCU)
- Liquid Air Mixing System (LAMS)
- Low Differential Pressure Generator (LDPG)
- Mapping Analysis and Planning System (MAPS)
- Particle Fallout Monitoring System (PFM)
- Portable Ultraviolet Flame Simulator (PUFS)
- Remote Monitoring and Alarm System (RMAS)
- Supersonic Gas-Liquid Cleaning System (SGLCS)
- Test Aerosol Generator (TAG)
- Turbine-Driven Pipe-Cleaning Brush (TDPCB)

Key milestone:

- 1999: Ongoing identification of alternative commercial applications for additional NASA-developed technologies.

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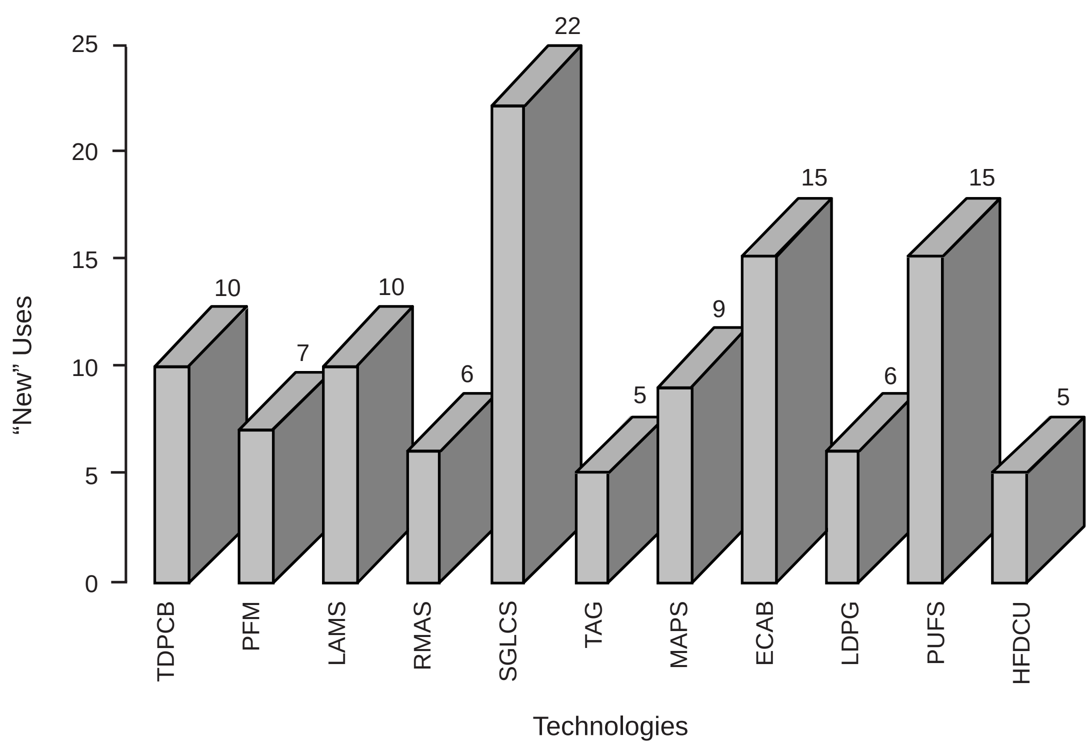
Participating Organizations: NASA Technology Programs and Commercialization Office (K.W. Poimboeuf and D. Makufka) and Florida International University (I. Becerra-Fernandez)



"New" Technology Uses

Management Support Systems: KSC Customer Focus Process Development

As part of the KSC Strategic Roadmap, customer satisfaction has been identified to be both an objective and a strategy. These customer satisfaction objectives and strategies will support the Center's vision and will help in achieving KSC's stated goal as the worldwide launch site of choice. The objectives and strategies will also drive improvements in KSC's core capabilities by addressing the tools, expertise, facilities, and business processes that support the customer. To address these customer satisfaction objectives and strategies, research was conducted in customer satisfaction, which included customer elements from the Baldrige award criteria and President's Quality Award. Based on the research, a customer focus model was developed (see the figure). The model delineates a six-element scope defined as follows:

1. Customer Knowledge: This element defines and segments current and potential strategic customers and identifies their needs, with additional information gathered regarding their requirements, expectations, and critical success factors.

2. Customer Satisfaction Determination Tools and Methods: These processes include collecting feedback from multiple types of methods over the duration of the customer experience at KSC, feeding that information back to the appropriate organizations, using the information to drive improvement projects, and reporting the improvements back to the customer.

3. Benchmark Best Practices: Benchmarking becomes an ongoing process of seeking out continual improvements in both the practices and processes of improving customer satisfaction.

4. Customer Satisfaction Leadership: This element uses the previous element results to create a customerkeeping vision, to saturate KSC with the voice of the customer, and to develop performance expectations related to customer focus.

5. Relationship Management: Relationship management uses processes for interfacing and supporting the customer to maximize customer loyalty and retention and analyzes complaints and lost customers.

6. Customer Satisfaction Improvement and Results: This element develops and tracks customer service standards based on outcomes from the previous elements, including customer satisfaction metrics and customer business results for KSC.

This model is being used as the blueprint to develop and implement processes and leadership for a customer-driven KSC. Once implemented, the results of the processes will be used as an integral component of the Center's strategic planning efforts.

Key accomplishments:

- 1998: KSC customer base identified and segmented. Surveyed KSC management for perceived barriers and enablers of customer satisfaction. Completed a test case for the first segment for customer satisfaction determination. Reported the test case results to senior management and to those customers interviewed.

Key milestones:

- 1999: Determine customer satisfaction baseline for all segments. Refine processes for all customer focus elements. Develop an Integrated Management System to assimilate customer data. Train KSC employees for customer awareness and understanding of customer processes.

- 2000: Implement the Integrated Management System. Establish and use processes for ongoing customer satisfaction measurement.

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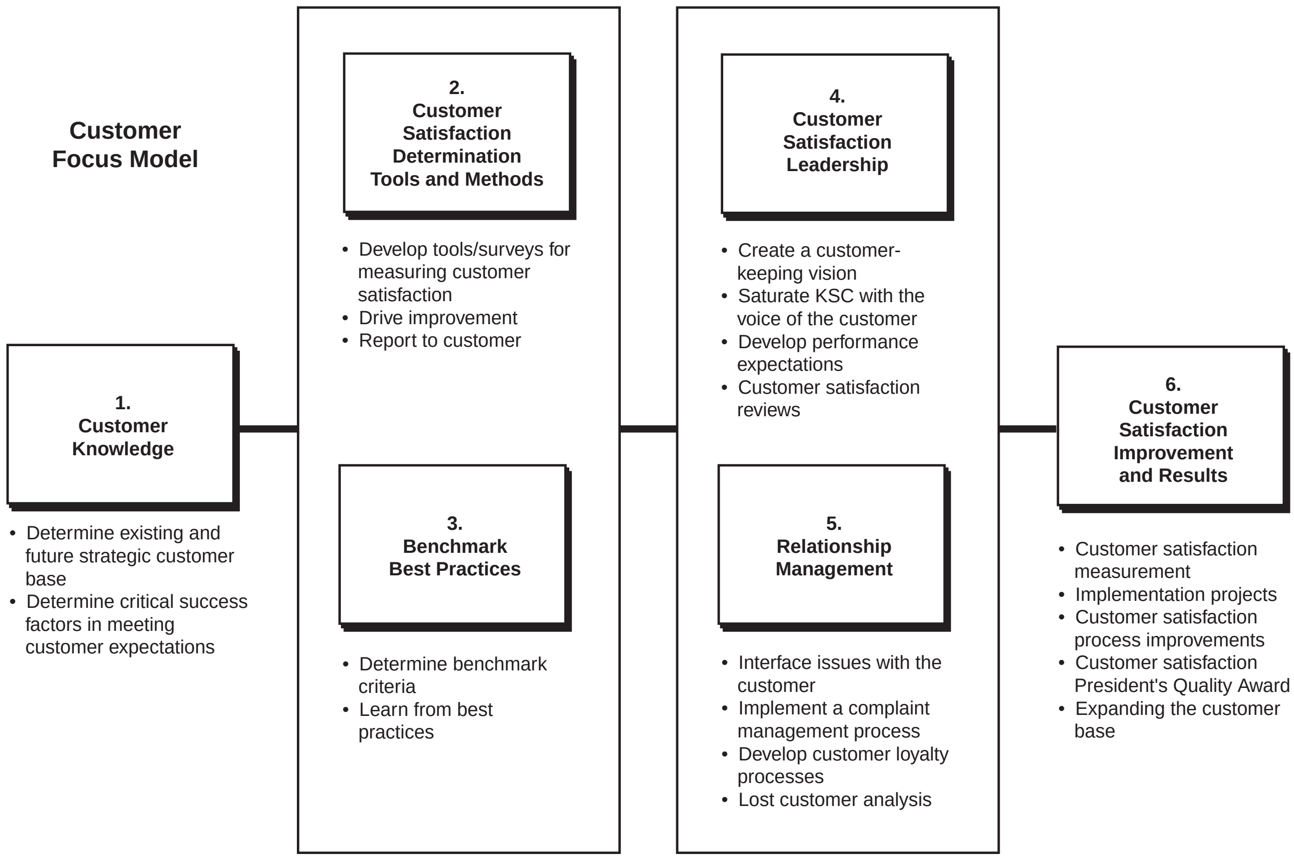
Participating Organizations: University of Central Florida (J. Matkovich and T. Kotnour) and the KSC Customer Focus Team (NASA, United Space Alliance, and Boeing)



Customer Focus Model
1. Customer Knowledge
• Determine existing and future strategic customer base
• Determine critical success factors in meeting customer expectations
2. Customer Satisfaction Determination Tools and Methods
• Develop tools/surveys for measuring customer satisfaction
• Drive improvement
• Report to customer
3. Benchmark Best Practices
• Determine benchmark criteria
• Learn from best practices
4. Customer Satisfaction Leadership
• Create a customer-keeping vision
• Saturate KSC with the voice of the customer
• Develop performance expectations
• Customer satisfaction reviews
5. Relationship Management
• Interface issues with the customer
• Implement a complaint management process
• Develop customer loyalty processes
• Lost customer analysis
6. Customer Satisfaction Improvement and Results
• Customer satisfaction measurement
• Implementation projects
• Customer satisfaction process improvements
• Customer satisfaction President's Quality Award
• Expanding the customer base

Management Support Systems: Balanced Scorecard Metrics

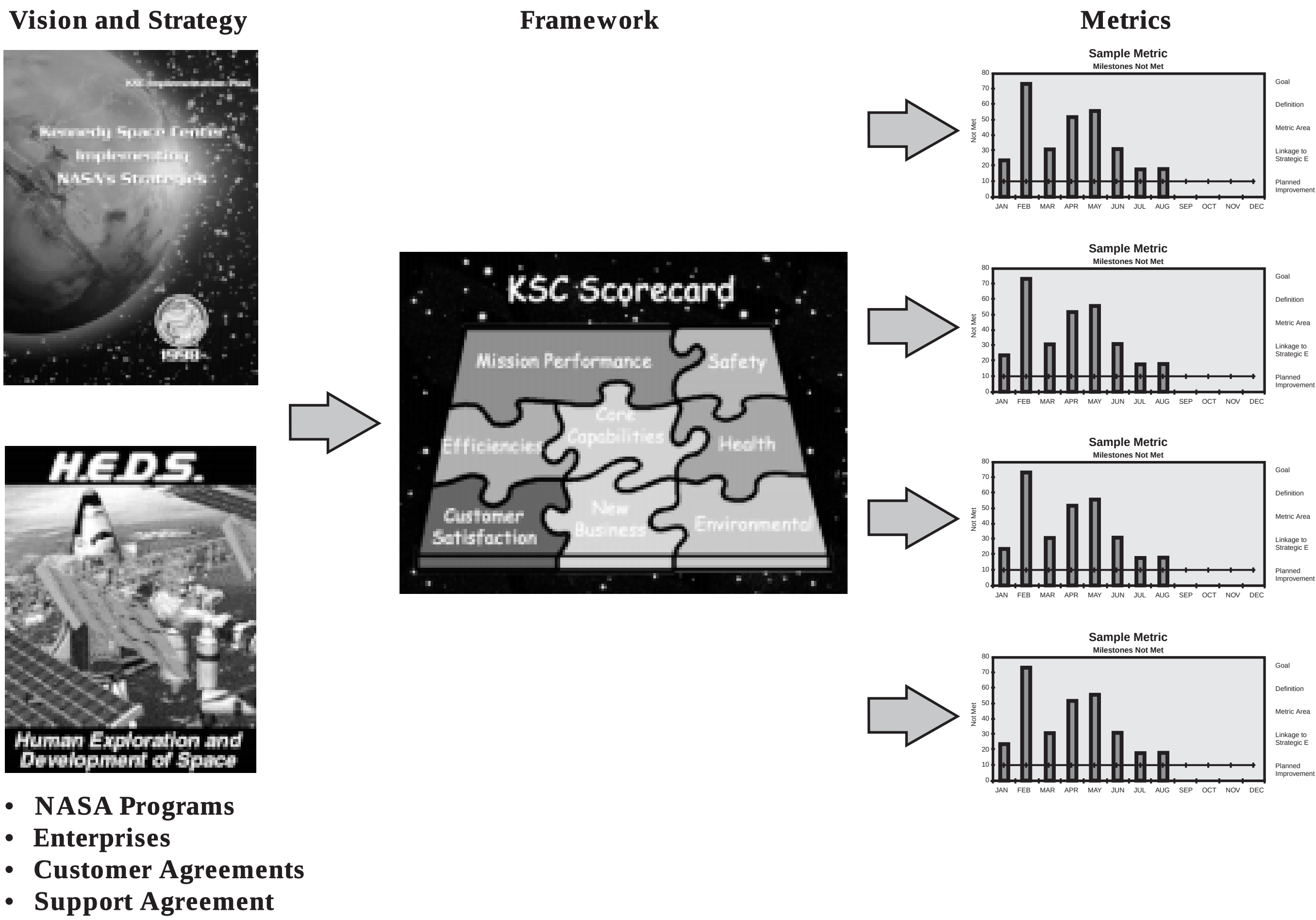
Due to the requirements of the Government Performance and Results Act of 1993, which was designed to improve the accountability of Federal agencies, and to KSC's commitment to manage strategically, selected indicators with performance targets were needed to evaluate the Center's performance. The KSC Strategic Roadmap had been developed; however, to bring the roadmap to life, measures were needed to determine if the strategy was being implemented and getting results. A lesson learned from the National Performance Review study on metrics suggested that a specific framework should be defined to develop measures of organization performance.

A team representing all areas of the Center was formed to analyze the existing strategy and to understand the expected outcomes from implementing KSC's strategy. A review of the literature on organizational measurement systems and input from experts was balanced with KSC corporate knowledge of current operations. Small groups were used to facilitate inspection of the category functional areas. The Agency, enterprises, and Center management were viewed as customers of the process. Seventeen high-level indicators that were balanced between near-term and long-term outcomes were selected. These metrics map to Agency and Center goals and form the KSC balanced scorecard.

As each high-level metric is developed, it will be added to the champion organization's Web site and linked to the KSC Business World Scorecard. The scorecard will be reviewed each quarter at an executive management review. A "drill down" to lower level metrics that track to root cause/individual contributors will be added. Each organization will be tasked to define a "balanced scorecard" related to its products and services.

Key accomplishments:

- November 1997: Senior managers reviewed each strategy in the KSC Roadmap and attempted to further define them with metrics.
- December 1997: 187 metrics were identified, at least one for each strategy and objective of the KSC Roadmap.
- January 1998: A team was formed to refine the indicators for consistency and linkage.
- March 1998: The team began to define a framework/approach for KSC metrics.
- April 1998: Roadmap indicators were grouped into eight categories and evaluated to balance across the Kaplan and Norton model.
- May 1998: The Center Director introduced the KSC Scorecard at a Strategy Update Briefing to all employees.



KSC Organizational Performance Measurement Structure

- August 1998: Top-level indicators were selected for each scorecard category.
- October 1998: Directorates were selected to champion each top-level metric.
- November 1998: The KSC Scorecard was added to the Business World Web site with place holders for each metric chart.

Key milestone:

- February 1999: A Center Performance Review was made using KSC Scorecard metrics.

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Participating Organizations on the KSC Metrics Integrated Product Team: AF-A (G. Swanson), AB-G2 (D. Armstrong), AI (R. Sharum), BC (L. Buckles), EC-C (R. Tilley), EY-B-PA (B. Monson), FF-D1-A (R. Ponik), FF-I3-A (M. Steele), GG-C-B2 (K. Buchner), HM-E (L. Boyd), JJ-5 (C. Quincy), LO (B. Franklin), LO (M. Stelzer), MM-H (A. Heard), OP-OSO (M. Krisberg), PH (S. Robling), PZ-A1 (T. Barth), and ST-B (J. Kunz)

Management Support Systems: Program Corporate Memory — a Knowledge Repository for KSC

Many organizations depend on decisionmakers to create mission-critical decisions that are grounded on information from various areas. The typical decisionmaker has a deep understanding of specific domains that affect the decisionmaking process combined with the experience that permits the individual to react immediately and decisively on the knowledge. A prominent decisionmaker has also gained extensive experience and implicit knowledge from years of work in such domains. An advancing trend today is downsizing; many organizations make a conscious decision to downsize in order to cut back spending and better compete in an increasingly aggressive market. Among the many side effects of downsizing is the dissipation of the "knowledge resources" of the organization; hence, organizations end up devitalized (e.g., decreased morale, commitment, quality, teamwork, productivity, and innovation). To conserve the existing knowledge, a practical knowledge management (KM) system demands that it be obtained/produced, shared, regulated, and leveraged by a steady conglomeration of individuals, processes, information technology applications, and organizational culture. KSC is currently facing a wave of employee turnover as a result of Federal Government downsizing, retirement, and work redefinition. In order to prepare for these imminent organization challenges, KSC commissioned a Knowledge Management Assessment (KMA) study.

In order to assess the areas of intellectual capital for KSC, a KMA was designed and implemented. The purpose of the KMA was to (1) identify key competencies for KSC, (2) perform a knowledge asset inventory, (3) perform a process evaluation, (4) analyze KM cultural readiness, (5) perform a technology evaluation, (6) develop a KM strategy deployment roadmap, and (7) propose the necessary next steps.

For this purpose, a series of KM assessment interviews were designed and implemented with the cooperation of representatives from the majority of the functional groups at KSC. The goal of the KM interview was to assist KSC in identifying key competencies and to analyze the current knowledge architecture for the Center. This step will ensure the appropriate methodology is recommended at the end of this phase. An important desired goal of this effort was to gather data to implement a prototype that will address some of KSC's KM needs.

Anecdotal results of the KMA interview for two functional directorates at KSC are described in detail in the project's final report. The findings from the KMA included KM needs and possible enhancements to the existing KM environment. These findings also comprise cultural needs, which address the promotion of a knowledge-sharing culture versus a culture where "knowledge is power."

Key accomplishments and milestones:

- A KMA study was designed and implemented between February and April 1998. In order to accomplish the assessment, eight technical groups were interviewed at KSC. The KMA findings obtained from the groups interviewed revealed KSC's KM needs and possible enhancements to the current KM environment.
- Following the KMA interviews, two directorates were selected by KSC executives for a 3-hour detailed second-stage drill-down interview. The two groups chosen were the Shuttle Processing and the Payload Processing Directorates. The purpose of the second-stage drill-down interviews was to identify a focus area to serve as a test bed for a KM application. Representatives from the two functional directorates were interviewed during the second-stage KMA.
- Illustrative prototypes were generated for each of the four recommendations presented to KSC executives. The prototypes were created using data from the groups at KSC. Findings were presented to the executive team in July 1998.

- A written report was compiled and distributed to the executive team as well as to each of the participating directorates in July 1998. The written report also included a literary review on what organizations are currently doing in KM.
- A number of presentations were made to some of the functional groups that participated in this effort. Ongoing presentations are expected.
- Proposals to address some of the required organizational KM systems were prepared and submitted.

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Participating Organization: Florida International University (I. Becerra-Fernandez)

KMA Summary of Findings: Knowledge Management Tools
(Number of Functional Groups With Need for KM Tool/Total Functional Groups Interviewed)

• Expert Knowledge Elicitation and Virtual Mentoring Tools: 6/8 Elicit, capture, and transfer the knowledge of experts acquired through the years of experience at NASA
• Expert Seeker: 6/8 Skills database with pointers to experts with a particular background
• Collaborative Tools: 6/8 Internet/intranet based tools that capture knowledge as teams create it
• Decision Support and Expert Systems: 5/8 Enhance decisionmaking and facilitate the decision process by incorporating knowledge factors from past projects
• Centerwide Lessons Learned Repository: 5/8 Include a synopsis of why certain decisions were made, rather than simply which decisions were made
• Knowledge Management Procedures To Harvest Knowledge: 5/8 Procedures to harvest organizational knowledge
• Electronic Document Storage: 4/8 Would allow departments and teams to share work files and relevant data
• Centerwide Self-Assessment: 1/8 Tool to identify what is organizationally known and what is unknown
• Translation Software: 1/8 For NASA documents and Web pages

Human Factors Engineering: Root-Cause Analysis System

The Root-Cause Analysis (RoCA) system helps engineers analyze and track the root causes of process anomalies due to human factors issues at the organizational, team, and individual levels. Such process anomalies include incidents that cause personnel injuries, damage facilities, incur additional costs, or delay processing. The system is being implemented under a Phase II Small Business Innovation Research (SBIR) contract. (RoCA is the new name of a system originally called HF-TAS, for Human Factors Trending and Analysis System.)

The development of RoCA is motivated by the weaknesses of existing root-cause analysis techniques. Although statistical quality control methods (i.e., methods for assessing whether a process is in control) are quantitatively robust, widely used, and successful, only very simple qualitative methods (e.g., fishbone diagrams) are available for root-cause analysis (understanding why a process is not in control). The result is that industries frequently spend millions of dollars fixing the wrong process problems. The other major motivation for RoCA is the focus on the importance of human factors in industrial accidents. Research has shown that avoidable human errors are a significant source of process anomalies in many industrial processes (e.g., aircraft manufacturing and maintenance).

RoCA has many possible KSC, NASA, and commercial applications. The first application of RoCA at KSC is assisting the Human Factors Team in investigating and analyzing the contributing causes of Shuttle ground processing accidents. The major technical innovation of RoCA is the anomaly process diagram (APD). The APD is a new, theoretically well-founded methodology for root-cause analysis focused on the representation of causal, probabilistic relations between process variables.

RoCA is being developed through rapid prototyping with significant design inputs from the eventual user community (i.e., the Human Factors team). Major upgrades to the software were delivered every few months in FY 1998. The latest delivered version includes a new "qualitative analysis" module for graphically editing and relating the contributing factors in an event investigation through an anomaly process diagram. It also includes a variety of predefined, standard reports the user can produce with only a few mouse clicks. These software capabilities build upon previously delivered versions to help human factors analysts perform event analyses, communicate their analyses electronically, and understand the trends in the mishap data using on-line analytical processing (i.e., pivot table) technology. Future versions of the system will extend the qualitative analysis capability to perform analyses quantitatively.

Key accomplishments:

- 1995: Phase I SBIR contract awarded.
- 1996: Completion of the Phase I feasibility study and demonstration software.
- 1997: Award of the Phase II SBIR contract. Developed and delivered the initial software prototypes to KSC.
- 1998: Delivery of the first RoCA system for operational use. Commercialization success of NASA-sponsored technologies through small business acquisition. KSC decision analysis workshop.

Key milestones:

- 1999: Refinement of operational prototype at KSC. Additional commercialization of RoCA and anomaly process diagram technologies. Decision analysis workshop at Johnson Space Center supporting the Exploration Office.

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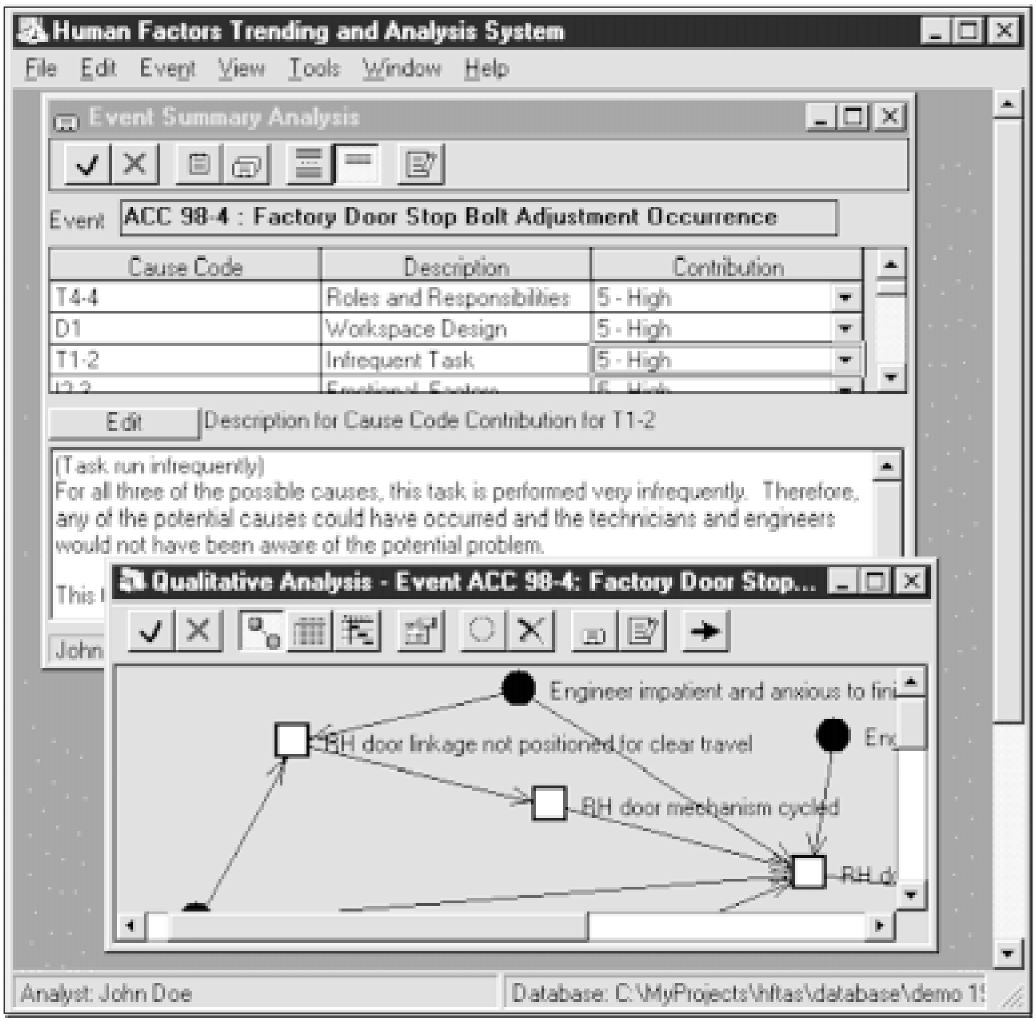
Participating Organizations: Prevision, Inc., which is now part of Fair Isaac, Co. (R. Fung and B. Del Favero); United Space Alliance; NASA/Ames; and NASA/KSC (Shuttle Processing and Human Factors Integration Office)



RoCA Analysis Entry Display

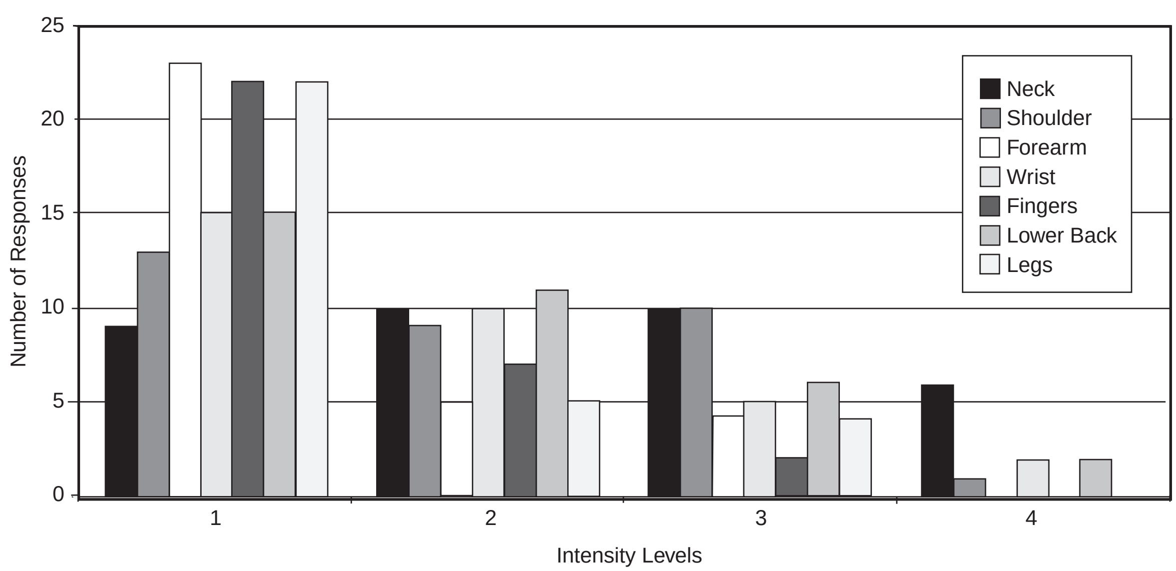
Human Factors Engineering: Applications in the Checkout and Launch Control System

KSC is recognized as NASA's Center of Excellence for launch and payload processing systems. Due to the continually increasing maintenance costs, technological obsolescence problems, limited system flexibility, and desire for improved Shuttle processing efficiencies, a new launch system is being developed. The Checkout and Launch Control System (CLCS) will replace the current Launch Processing System (LPS). By increasing system reliability and reducing the hardware, software code lines, and facility space, the team projects a yearly operational cost savings of 50 percent once the new system is fully deployed.

Human factors is a specialty concerned with the well-being of people in complex systems. It focuses on human beings and their interaction with products, equipment, facilities, procedures, and the environment. Three major human factors applications on the CLCS project are:

- Ergonomic assessment: An ergonomic assessment survey was developed for the CLCS project personnel. Overall, the availability of basic ergonomic aids was determined to be low. Participants rated the intensity and frequency of pain or discomfort they feel in various areas of their bodies. The figure summarizes the pain intensity reported in the survey. Neck, shoulder, and lower back were the areas cited with the greatest frequency and intensity of pain among the CLCS personnel.

- OMI conversion: Operations and maintenance instructions (OMI's) are the written work



Intensity of Pain

instructions used to process Shuttles and payloads. These provide detailed step-by-step instructions for engineers, technicians, and inspectors participating in the various operations and were written for the existing LPS. As the new CLCS software is implemented, the existing work instructions will need to be modified for the new system. A work measurement analysis was performed to estimate the time required to convert these OMI's. Approximately 950 OMI's from 24 Shuttle systems were reviewed. Due to the uncertain nature of the conversion process, "best case," "worst case," and "most likely" scenarios were developed.

- MMT console design: A significant portion of the CLCS project is the replacement of the existing equipment in the firing rooms. Several console designs were considered for the Mission Management Team (MMT) working in the firing rooms. Five ideas were developed for the MMT console designs. Console design and vendor selection is ongoing.

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Participating Organizations: University of Missouri-Rolla (S. Murray) and Lockheed Martin

Human Factors Engineering: Human Error Research in Shuttle Processing and Aircraft Maintenance Operations

Numerous safety studies have shown that the causes of aviation accidents and incidents are more likely to be related to human error than mechanical failure. However, human error may occur both in flight and in the ground operations that support them. Several recent aviation accidents have determined the probable cause to be maintenance related.

Thus, there is a growing recognition of the importance of maintenance human factors and the need for operational research. Past accidents have dramatically demonstrated the potential impact of human error problems in maintenance areas such as training for maintenance and inspection, tracking of maintenance responsibility, procedures and task documentation, work environment conditions, verbal and written communications, and leadership and teamwork.

Although the aviation industry has been innovative in developing flight training technologies, human-centered automation, multimedia information, and decision-aiding systems, the adaptation and transference of human factors tools, techniques, and principles to ground operations have been limited. The goal of this research is to better understand human error in maintenance operations in order to improve procedures, training interventions, and other maintenance task aids that will ultimately reduce human error and enhance safety in maintenance operations.

Striking similarities in human factors issues across Shuttle and aircraft maintenance have led to technology transfer meetings on topics of mutual interest. Figure 1 shows the Shuttle in the Orbiter Processing Facility, which has a work environment and work processes similar to those in depot-level aircraft maintenance centers (see figure 2).

This Ames Research Center (ARC) and KSC collaboration is intended to (1) promote human factors awareness, (2) exchange research information and results, and (3) when feasible, conduct joint human factors research using KSC's unique technology test bed capabilities. These goals are being accomplished in the following ways:

- Technology transfer workshops: The overall goal is to identify issues, problems, and "lessons-learned" in common interest areas across spacecraft processing and aircraft maintenance. Topics such as human error and incident analysis, risk analysis techniques, human factors training, and human performance measurement are included.

Figure 1. Space Shuttle Orbiter Entering Its Maintenance Facility

Figure 2. Aircraft Engine Maintenance

- Human factors research: The goal is to combine research efforts that involve similar human factors goals and issues across multiple operational settings. KSC provides a test bed for operations research in depot-level maintenance.

These efforts demonstrate an area of synergy between NASA's Aeronautics enterprise and Human Exploration and Development of Space (HEDS) enterprise. In 1998, the NASA Aviation Safety Program initiated an element focusing on human factors in aircraft maintenance operations. This program is closely coordinated with the Federal Aviation Association and supports many research efforts that can also apply to Shuttle operations. This opportunity has been used to increase the collaboration between ARC and KSC and look forward to valuable results supporting the goals and objectives of both enterprises.

Key accomplishments:

- 1991 to 1993: Initial application of human factors technologies developed for flight crews to aircraft maintenance crews. Team effectiveness research on Shuttle maintenance crews. Memorandum of understanding between ARC and KSC signed.
- 1994 to 1995: Initial collaboration with the KSC Shuttle Processing Human Factors Team in the area of human error investigation and analysis.
- 1996: Incident Investigation Workshop hosted by ARC. This workshop focused on the human factors aspects of incidents, accidents, mishaps, and close calls in spacecraft and aircraft maintenance.
- 1997: Human Factors Training Workshop hosted by KSC. This workshop focused on human factors training issues.
- 1998: Written Procedures Workshop hosted by KSC. This workshop focused on work instructions and task analysis (two task areas in the Aviation Safety Program, Human Factors in Maintenance) and supported the Shuttle Work Instruction Task Team and airline and military maintenance operations. Memorandum of understanding between ARC and KSC updated and signed by the Center Directors.

Key milestones:

- 1999: Continued collaboration in incident investigation, root-cause analysis, and task analysis. Possible workshop focusing on statistical process control applications to system performance data collected during maintenance operations. Formalize the KSC process/industrial engineering test bed.

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Participating Organizations: United Space Alliance, Transport Canada, National Transportation Safety Board, Aerospace Safety Advisory Panel, Northwest Airlines, United Airlines, Continental Airlines, U.S. Airways, Idaho National Engineering and Environmental Laboratories, Federal Aviation Administration, and U.S. Air Force

Work Methods and Measurement: Expert System To Generate Job Standards

KSC industrial engineers are actively engaged in identifying techniques to improve the efficiency and effectiveness of Space Shuttle ground processing. One approach that has demonstrated a high potential for success is the use of industrial engineering techniques to measure work. Although many work measurement techniques are best suited for short-duration, high-repetition activities, there are also approaches to successfully measure the time associated with long-duration, low-repetition tasks like those inherent in Shuttle ground processing.

A challenge to work measurement practitioners is that there is no guidance on which of several available measurement techniques to use. Practitioners must rely on their own experience, on-the-job training, previous approaches used by their predecessors in the organization, and trial and error. These methods for choosing a work measurement technique can lead to ineffective results. The literature is of little help and there are no references to guide the practitioner. KSC industrial engineers have recognized this deficiency and have taken steps to fill the void.

In 1994, KSC industrial engineers and their support contractors began to develop an expert system to (1) help the job standards developer select an appropriate measurement technique and (2) guide the job standards developer through the steps required to develop a job standard when using a work time estimation technique. The Job Standards Development System (JSDS) delivered to KSC in 1998 asks questions relevant to technique selection and, on the basis of responses by the user, provides a list of techniques suitable for the application. If desired by the user, the JSDS will recommend a specific technique determined to be appropriate for the application defined by the user.

When estimation is the appropriate technique, the system guides the user through data acquisition from the domain expert and computes the standard time of the job. In addition to providing the standard time, the system provides an estimate of job duration and information about each resource required to complete the job.

The JSDS has two primary applications. First, any organization that develops job standards (or less formal job time estimates) would benefit from the expertise embedded in the work measurement technique selection module of the system. Second, the system will help organizations document and quantify skill and work time requirements for work composed of long-duration, low-repetition tasks. This type of work is often associated with equipment and facility maintenance activities and functions. The JSDS extends supply chain management down to the individual task level since job time estimates are an important ingredient to project scheduling. Candidates for commercial application of the JSDS include operations of state and local governments, health care facilities, public utilities, and aircraft, rail, and ship maintenance and repair facilities.

Key accomplishments:

- 1994: Successfully demonstrated the prototype expert system to select an appropriate work measurement technique.
- 1995: Identified the work measurement techniques to include in the expert system.
- 1996: Conducted a small-scale test of a work measurement technique in the KSC environment.
- 1997: Conducted a comprehensive field trial of the work measurement technique tested in 1996.
- 1998: Completed the development of the JSDS. The JSDS includes expert systems that select a work measurement technique, guide the measurement of work when work time estimation is appropriate, and compute the job standard.

Key milestone:

- 1999: Ongoing identification of commercial applications.

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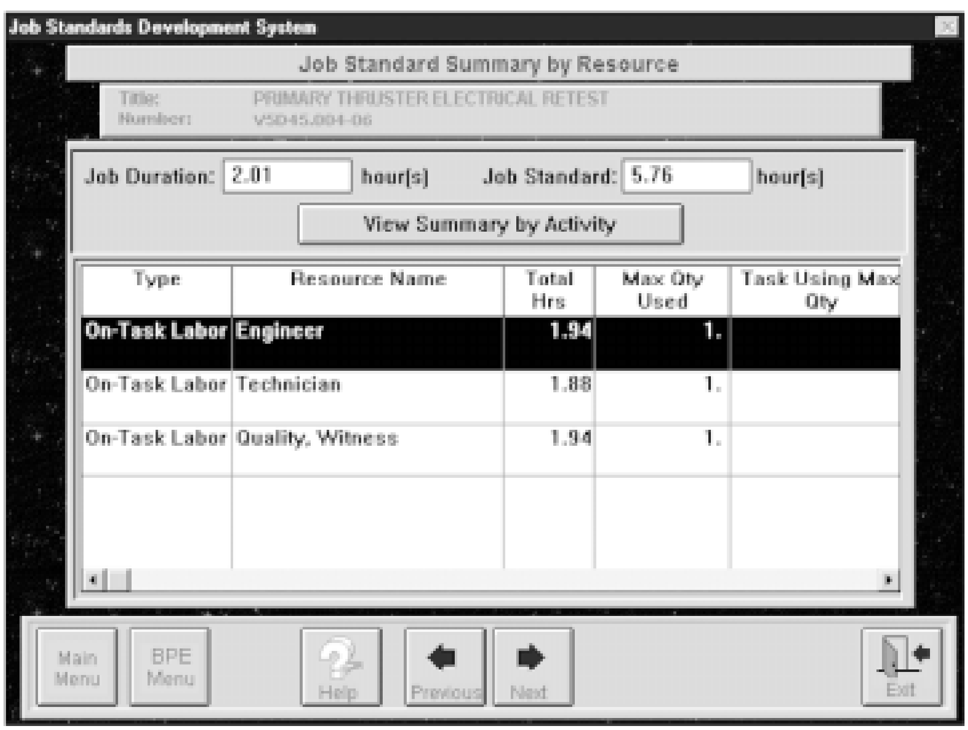
Participating Organizations: OMNI Engineering and Technology, Inc. (N. Schmeidler), Affinity Logic Corporation (G. Ribar), and United Space Alliance



Job Standard Summary

Work Methods and Measurement: Electronic Portable Information Collection

Work procedures for payload processing and checkout operations at KSC are executed using a paper system. With this system, a procedure is generated using a word processor. The procedure is then printed out, copied, and distributed to members of the task team. When the work procedure is executed, a single master copy is kept up to date by using a pen to record the test data and notes and by using quality and technician ink stamps to verify the work steps as they are performed. Test team members maintain their own copies of the procedure. Deviations to the work instructions that occur during the execution of the procedure must be documented on a paper form. These deviations require approval signatures. Once approved, the deviation is copied and distributed to the task team. The completed master work procedure, including deviations, is scanned into a computer and stored electronically.

The Electronic Portable Information Collection (EPIC) system was developed to automate this procedure. EPIC was formerly known as the Portable Data Collection (PDC) System. With the EPIC system, the procedure is converted from a word processor document to a database. It is then executed using portable computers. Data is entered electronically, either with a keyboard or a pen, using handwriting recognition. The system distributes this data to all other terminals. The ink stamp is replaced with an electronic stamp that meets the form, fit, and function of the old ink stamp. A programmable memory chip inside the electronic stamp stores a unique identifier. All team members have their own electronic stamp.

This electronic stamp adds a secure mark to a step, identifying who performed that step and the date and time the step was performed. The electronic stamp is read using a stamp reader connected to the serial communication port of the computer. The system provides protection mechanisms to ensure data and stamp integrity. Once the procedure has been worked to completion, it is converted to a portable document format (PDF) and stored electronically in a documentation system.

The main components of the EPIC system are the central data server (CDS) and the portable data terminals (PDT's). The CDS is the main computer that serves as the network host and database server. PDT's display procedure steps and enable users to collect test data and stamps. The PDT's are standard personal computers (PC's) running Windows 95 or Windows for Workgroups operating systems. Various PC's are used as PDT's, including desktops, laptops, wearable computers, and pen-based tablets. The CDS is a high-end PC running the Windows NT operating system.

The project was developed jointly by Sentel Corporation and KSC, the lead center for payload processing. The prototype system was developed under a Small Business Innovation Research (SBIR) contract that was awarded to Sentel Corporation to develop the capability to capture technician and quality stamps and test data electronically. The operational version was developed under a Space Act Agreement between NASA and Sentel Corporation. The following benefits are provided by the EPIC system:

- All test team members see changes to the document instantly, providing greater assurance that all team members are properly informed and the data is accurate.
- Accuracy of the procedure is improved as deviations are incorporated directly into the appropriate sequence of the procedure. The time to process, approve, and distribute a deviation is also reduced.
- Information availability is improved. Test data can be searched and retrieved through a standard database.
- Queries can be made for management reporting or incident investigations.
- The need to print and distribute procedures prior to testing is eliminated.
- The need to scan the procedure for storage is eliminated.
- Emergency procedures can be accessed immediately.
- Paper usage is reduced.

Team Members Using EPIC

The system was modeled after the existing paper system using the existing business rules. Presently, the system is being developed to support Space Station processing. EPIC is being marketed to the airline industry for use in airplane maintenance and to the electrical power industry for use in power substation maintenance.

Key accomplishments:

- 1993: Completed the Phase I study for the SBIR contract.
- 1996: Completed Phase II of the SBIR contract. Demonstrated the proof of concept for this system. Received the NASA SBIR Technology of the Year Award in the computer/ software category. Completed pilot study 1. The first pilot study was conducted in the Operations and Checkout Building using the EPIC electronic system in parallel with the paper system.
- 1998: Upgraded the system from a prototype to an operational system. In pilot study 2, tested the EPIC system in the KSC Space Shuttle Main Engine Shop and Space Station Processing Facility.

Electronic Stamp and Stamp Reader

Key milestone:

- 1999: Implement the EPIC system to be used by NASA, Government contractors, and private industry.

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Participating Organizations: Sentel Corporation (K.L. Jackson and M.R. Kappel) and Mississippi State University (L.K. Moore)

Work Methods and Measurement: Work Instruction Task Team

The Shuttle Processing Work Instruction Task Team (WITT) was chartered to develop and implement a comprehensive vision for future work instructions used in ground processing of the Space Shuttle fleet. The goals of the new work instruction system are to improve the efficiency of the processes used to generate and maintain the written procedures, to improve the efficiency of shop floor task execution using the new procedures, and to improve workplace safety by reducing the potential for human errors.

The team analyzed the current work instruction generation processes and products (the written procedures). Several opportunities for improvement were identified to improve the cycle time and to reduce the labor hours associated with delivering the work instructions to the shop floor to support a specific task. Existing work instructions are rule based, are highly detailed, and frequently contain information not needed for a specific task. Examples of nonvalue-added information include drawings for other orbiter vehicles and work steps for testing only performed at specified intervals. The written procedures varied widely in “look and feel” for the users, which will become increasingly important as workers are more frequently assigned to different orbiter and ground systems or different facilities.

The WITT collected data from approximately 20 different KSC teams working on various aspects of improving work instruction processes. The team also gained valuable information and insight through participation in a Written Procedures Workshop co-sponsored by Ames Research Center and KSC. Finally, the team collected benchmark data during site visits to three different industry organizations. The result of the team’s research was a vision for the future of KSC work instructions based on the following eight key actions:

- Use a standardized format for the work steps in all Shuttle Processing procedures.

- Increase shop involvement in the authoring process.

- Deliver “lean, clean work instructions” with only the information needed for the current task and a level of detail consistent with the results of a task analysis con-

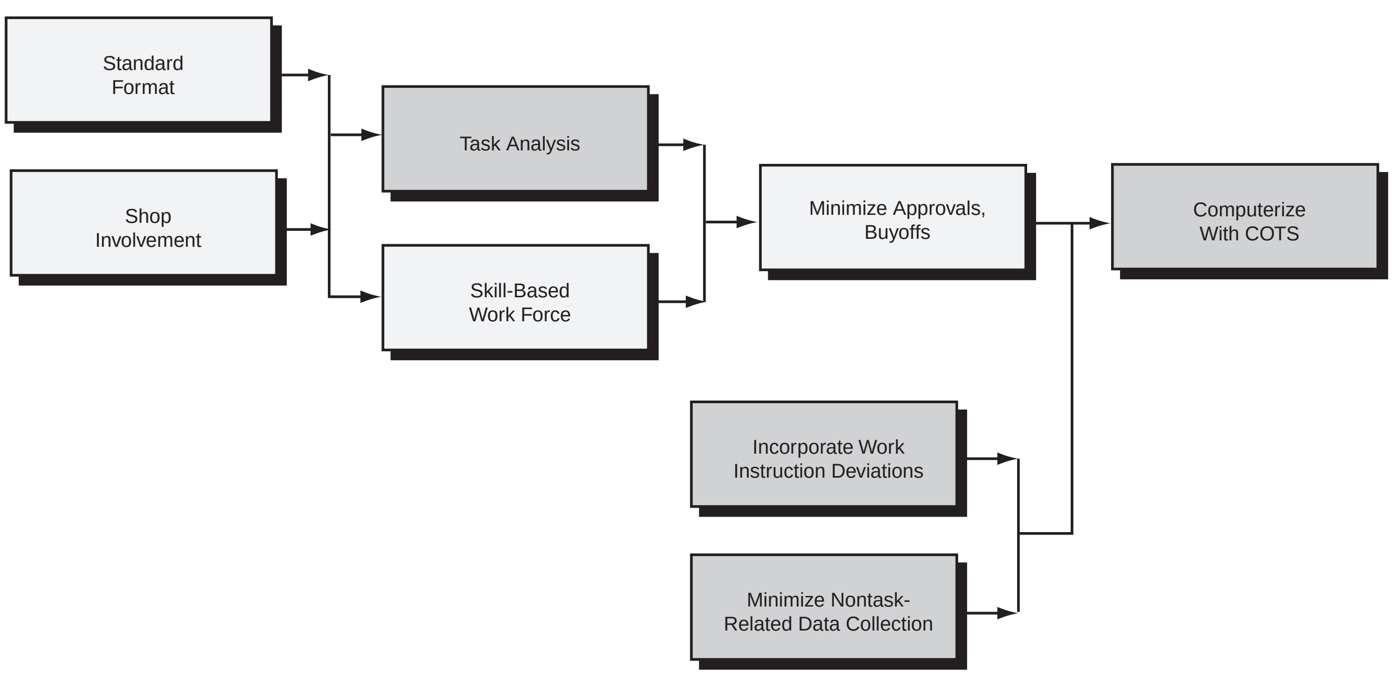

Figure 1. Key Elements of the Shuttle Processing Work Instruction Vision

sidering task frequency and criticality / complexity.

- Take advantage of KSC's skill-based work force.
- Minimize approval, buyoff, and closure requirements.
- Incorporate all permanent, successfully executed work instruction deviations prior to release of the next revision.
- Optimize the data collection processes through innovative methods to capture nontask-related data and ensuring that all data is analyzed and used.
- Use the latest commercial off-the-shelf technologies to enhance the new work instruction process.

The recommendations directly address the root causes of the systemic problems associated with KSC's written procedures. The relationship between the eight vision elements is shown in figure 1. The team also constructed several conceptual models showing the relationship between task frequency / complexity / criticality to the level of detail, skill-based training, and approval / buyoff requirements. The level of detail model is illustrated in figure 2.

Key accomplishments:

- 1998: Completed the work instruction vision and obtained approval from KSC and Space Shuttle Program management to begin implementation. Designed and implemented "test cases" to demonstrate the feasibility of the proposed new work instruction system. Supported a team to significantly reduce the number and complexity of the requirements for KSC work instructions. Developed a standardized format and writers guide (based on the Department of Energy's guide) for implementation in all areas of Shuttle Processing. Developed an initial KSC task analysis procedure with support from the University of Central Florida. Integrated efforts with several additional teams.

Key milestone:

- 1999: Charter implementation teams for all key vision elements.

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Participating Organizations: NASA Shuttle Processing (R. Blackwelder, M. Wilhoit, and G. Glochick), United Space Operations (D. Blankmann-Alexander, D. Ciccateri, R. Corsillo, S. Defillips, J. Entinger, C. Hannas, K. Jones, B. Kidd, B. McKenzie, S. Morrison, V. Neal, J. Rooker, J. Swanson, and C. Jones), and University of Central Florida (J. Pet-Edwards)

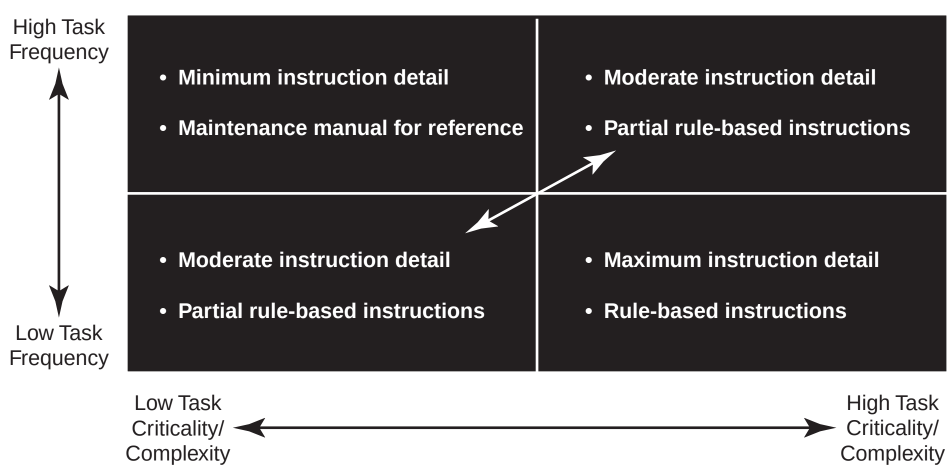

Figure 2. Work Instruction Level of Detail Model

Work Methods and Measurement: Industrial Engineering Decision Support Tool

The objective of this research was to develop a methodology for a user-friendly decision support software system for the application of innovative industrial engineering (IE) models and technologies for complex processes at KSC. To illustrate the feasibility of this approach, AET, Inc., developed a model for a KSC work process using historical data collected over 10 Shuttle missions.

The technical approach used for the modeling was the application of Multiple Regression Systems (MRS's) for estimation of indirect work content and performance. MRS applies the statistical technique of multiple regression to analyze the output of one or more operators engaged in a variety of tasks in order to estimate the time used to produce a single unit of output for each of the tasks. This model is shown in the equation:

$$Hours = 9.29 + 0.278 \cdot Seq001 + 0.235 \cdot Seq003 - 0.08 \cdot Seq005 + 0.547 \cdot Seq006 + 0.318 \cdot Seq008 + 0.017 \cdot Seq009 + 0.062 \cdot Seq024$$

The coefficients in the model equation have special significance. They may be used to estimate the average time required to complete a step in each of the sequences analyzed. For example, 0.278 man-hour would be the expected requirement for completing a step in sequence 001. For illustration purposes as well as data limitations, the assumption that all steps in an individual sequence require equal amounts of time was made. This equation may be used to predict the total man-hours required for any number of steps performed in any of the sequences.

The application of this model in the area of decision support is extremely powerful. This model can be used to support changes in sequence steps. By qualitatively predicting the number of work hours required, a direct link to labor cost is established. Therefore, a decision to change a process can be supported by objective data and not just subjective estimates. The prototype software system is shown in the figure.

Key accomplishments:

- 1998: Phase 1 Small Business Innovation Research (SBIR) project. Performed statistical analysis on data collected from a structural bonding experiment. Identified, together with KSC ground operations and IE personnel, appropriate work processes for analysis and modeling. Developed an analytical model of the process under study and gathered data for estimation of model parameters. Completed a final report specifying the technical results achieved in this project.

Key milestone:

- 1999: Potential continuation of research.

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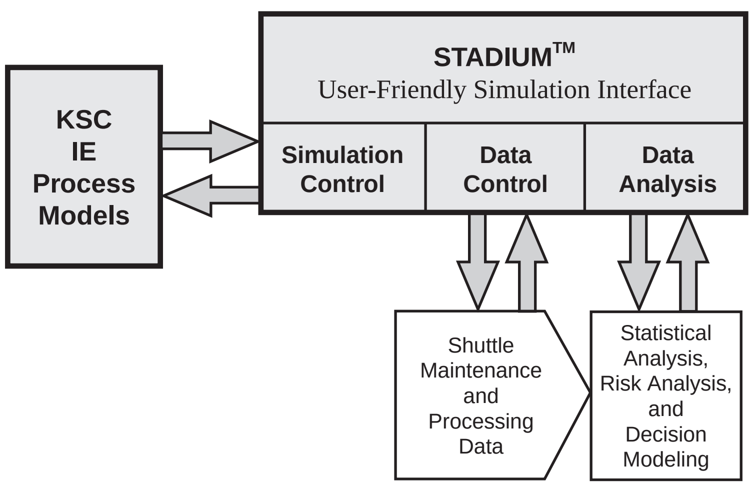
Participating Organizations: AET, Inc. (Dr. G.T. Hess) and Lehigh University (Dr. L. Martin-Vega)



Proposed Software-Based Decision Support System

General: Center for Applied Research in Industrial and Systems Engineering

A partnership was developed between NASA and Florida International University (FIU) to establish the Applied Research in Industrial and Systems Engineering (ARISE) Center. The partnership seeks to establish a combined research and educational program to attract and retain women, Hispanics, African Americans, and other individuals from minority groups to engineering. Students participating in the program:

- Are exposed and trained in NASA's mission.
- Are given seminars on a variety of issues, including the realities of the workplace, diversity, and gender issues.
- Participate in applied research projects.
- Are instructed on the benefits of pursuing postgraduate studies in the hopes of increasing their chances to succeed in the workplace as well as increasing their stature as role models for future generations.
- Have a 4-week on-site internship so they become acquainted with the various KSC processes needed to complete the projects.
- Receive a stipend during the academic year and the summer terms.

An important objective of this effort is to foster partnerships between FIU and NASA and between FIU and local industry. The initial partners in this effort were FIU in Miami, Florida, and KSC. FIU was the lead institution, whereas KSC provided steering guidance and was a source to implement some aspects of the program. The initial timeframe of this effort was 2 years. In this timeframe, it was expected that various aspects of the model should be tested, rethought, and retested as needed so the model could become an appropriate model for industry-university partnerships. Specifically, a proposal was developed to begin selling the model to local industry. The proposal highlights the benefits local industry may derive from the ARISE Center and the impact their sponsorship will have in shaping the lives of future community leaders.

Key accomplishments:

- 1997:
  - Established an applied research center where participating students have access to the necessary tools to start and complete industrial and systems engineering projects related to NASA operations and processes at KSC. Selected and set up hardware and software. Selected / purchased other equipment needed for the ARISE Center.
  - Recruited students, which involved the development of a brochure and the development of a Web site for adver-

tising the existence of this opportunity *(arise.eng.fiu.edu/)*. Students from under-represented groups who had a grade point average of 3.0 were identified and a letter of invitation was sent. Eight students were selected.
  - Developed activities for the ARISE Center that were attractive to students.
- 1998:
  - Purchased computer equipment and software. The Center has one server, two networked laser printers, and 15 PC's. The Center has licenses for a variety of software. The FIU industrial and systems engineering department provided laboratory space and furniture to house the Center.
  - Held six seminars, including an overview of NASA, Space Shuttle history and assembly process, and gender and racism in the workplace.
  - Visits to KSC for a special tour to see various processes at KSC. Students participated in a 4-week internship during the summer. This internship enabled them to work next to practicing engineers while developing their projects.
  - Students worked in teams of two on selected projects. Two projects were done for Logistics, two for Installation Operations, and one for the Checkout and Launch Control System (CLCS).
  - Curriculum Integration. Credit for projects was given as part of a technical elective course. The projects were presented in the Project Management course as well as in the 1998 Annual Industry Projects Conference.
  - One-to-one conversations were used to let the students know what graduate school is all about and how it can fit their career plans.
  - During the summer, a workshop was given on statistical analysis to the Payloads office personnel. New avenues of collaboration were investigated. New projects and liaisons were identified.
  - Fourteen students were recruited for the second year. New students will be selected in December 1998.
  - A proposal was prepared and is being discussed with local industry. The Web site is continuously being updated.

Key milestones:

- 1998: Discussion of projects occurred in January, August, and December. Project development occurred over the academic year. A Projects Conference was held in April, which showcased some of the projects to industry. Continued the Industrial Portfolio to recruit industrial partners. Seminars continued on a two-track level.
- 1999: Projects Conference in April. A conference paper and journal paper will be published.

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Participating Organization: Florida International University (M. Centeno and M. Resnick)

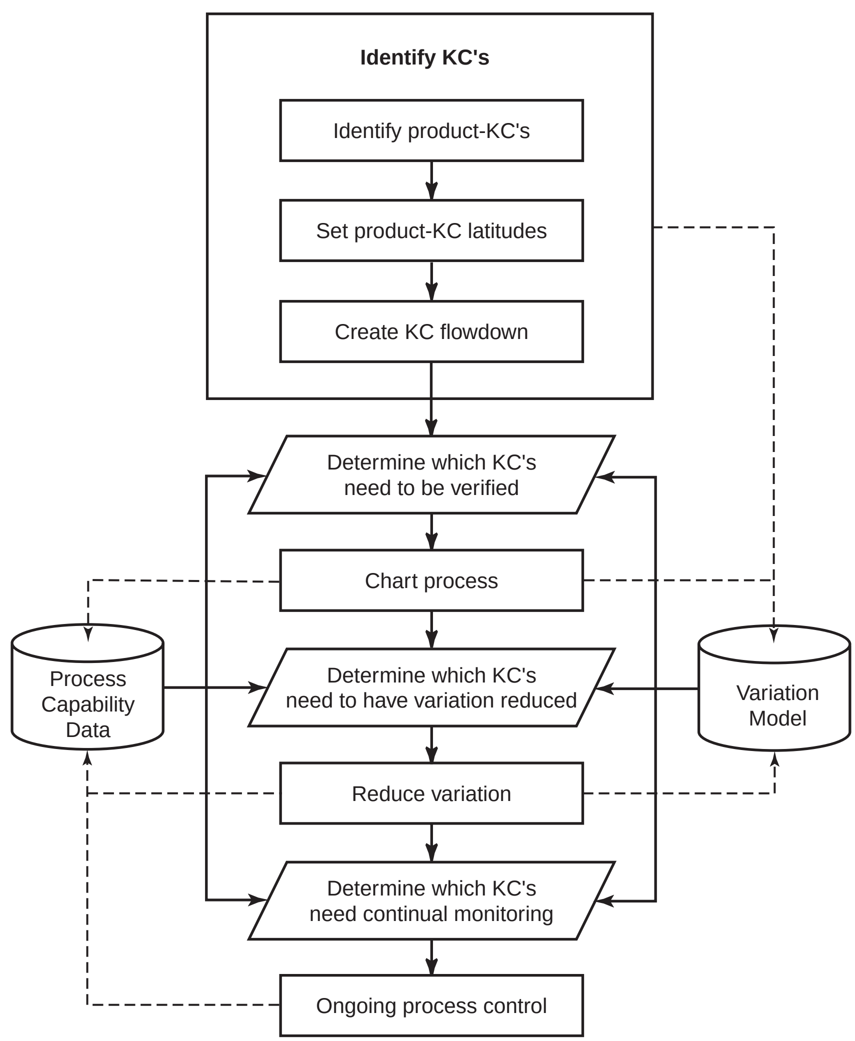
General: Key Characteristics in Manufacturing and Maintenance

Key characteristic (KC) methodologies are used by a wide variety of companies to help manage variation risk in the design and manufacture of complex products. Complex products can contain millions of dimensions and characteristics (voltages, forces, etc.), each of which impacts the performance of the product. In addition, each of these features as manufactured will deviate from its nominal value because of inherent variability in manufacturing, assembly, and environment. However, only a few of the millions of features, the KC's of the product, will significantly affect the final quality, performance, and cost of the product. The KC's of a product link the product requirements that are variation sensitive to the part and process characteristics that contribute to their variation.

KC methodologies include tools processes to identify the select features, assess their impact on the quality of the product, and mitigate the effect of their variation. Variation mitigation techniques include robust design, process control, variation reduction, and inspection. The figure shows a typical KC methodology.

The first annual KC Symposium in 1997 brought 40 people from 11 organizations together to discuss general problems and issues surrounding KC implementation. The 1998 KC symposium was hosted by KSC. Thirteen presentations included the following: Allied-Signal discussed the implications of KC's on suppliers; GE discussed the design for six sigma; Xerox, Kodak, and Boeing gave overviews and examples of KC implementations; and IBM gave a presentation on the implication of statistical tolerancing.

Four strategic research and development issues emerged from the 1998 symposium: how to take a system view of variation risk management, the meaning of KC's to suppliers, a potential U.S. standard for KC's, and the cost implications and benefits of KC methodologies. In addition, working groups were formed to continue discussions. These groups are: Costs, Standards, Statistical Tolerancing, Process Capability Databases, Metrology, Supplier Relations, and Models and Tools. Information about the conferences, the working groups, and other KC resources can be found at the Web site: *http://cardamom.mit.edu/KC/kc.html.*



Typical KC Methodology

Additional research and technology development was proposed by developing KC spinoff common interest groups. KSC does not have high-volume manufacturing operations like the organizations represented by most existing KC symposium participants, but the fundamental principles of statistical quality control (SQC) and key characteristics apply to many other areas. KC methodologies may require customization in order to be useful in KSC operations. Potential spinoff common interest groups could customize and apply basic KC and SQC methodologies to different domains. Two candidate spinoff areas are:

1. SQC applications to very low-volume or unique space hardware production: The potential exists to apply SQC techniques to the manufacture of low-volume or unique hardware elements. In these cases, the data elements are usually operating measurements of the machinery used to produce hardware rather than the hardware itself, since the extremely low-volume/unique products will not supply enough data for meaningful statistical analysis.

2. SQC applications to aircraft/spacecraft maintenance (test and checkout) data: NASA and United Space Alliance system engineers are currently applying SQC analysis techniques to Shuttle system performance data under the ongoing surveillance effort. The analysis results will support certification of flight readiness (COFR) and identification of enhancement opportunities. The KSC COFR process now involves verification of process stability and capability.

Key characteristic methodologies can be applied to select those system performance data sets most important for determining flight readiness and opportunities for enhancements and upgrades. Based on preliminary research, it appears that Department of Defense and industry aircraft maintenance centers could also benefit from additional applications of SQC tools to system performance data collected during maintenance operations.

Key accomplishments:

- 1997: First annual KC Symposium hosted by the Massachusetts Institute of Technology.
- 1998: Second KC Symposium hosted by KSC. Strategic project approved to pursue funding for development of key characteristic methodologies supporting KSC operations.

Key milestone:

- 1999: Third KC Symposium to be hosted by Motorola in Phoenix, Arizona.

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Participating Organizations: Massachusetts Institute of Technology (A. Thornton), Allied-Signal, Alcoa, British Aerospace, Chrysler Corporation, DARPA, Eastman Kodak, Ford, Embry-Riddle Aeronautical University, GE, GM, Honeywell, IBM, IDA, ITT, Lockheed Martin, NASA, NIST, Northrop Grumman, Pratt and Whitney, Quality Associates, Raytheon, Textron, Boeing, United Space Alliance, University of Florida, University of Maryland, and Xerox

General: Searchable Answer Generating Environment — a Knowledge Management System To Seek Experts in the Florida State University System

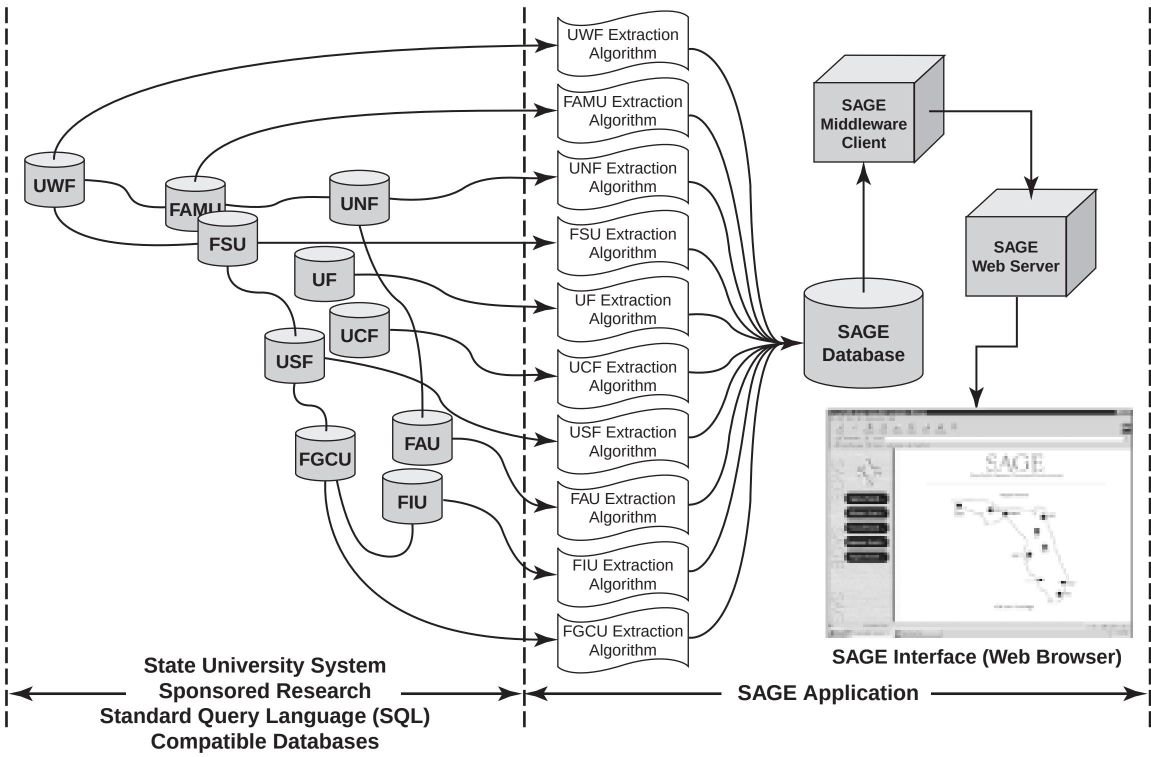
The need to acquire intellectual capital has created the Knowledge Management (KM) movement, which aims to develop new practices and tools to capture knowledge. An indepth examination of current KM projects revealed that a large percent attempt to create some kind of a knowledge repository. Current studies identify three types of knowledge repositories. One of these types attempts to manage organizational knowledge by storing pointers to those who have specific knowledge within the organization. In this light, this report discusses the development of the Searchable Answer Generating Environment (SAGE) application prototype. The development of this application prototype was funded through the NASA/Florida Minority Institution Entrepreneurial Partnership (FMIEP) grant.

The purpose of this KM system is to create a repository of experts in the State of Florida State University System (SUS). Currently, each of the state universities in Florida maintains a database of funded research, but these databases are disjointed and disparate. This application creates one single Web-enabled repository that can be searched in a number of ways including research topic, investigator name, funding agency, or university. The benefits of SAGE are: (1) SAGE is a repository of intellectual capital within the Florida SUS; (2) SAGE helps locate Florida SUS researchers for collaboration with industry and Federal agencies, thus increasing the potential for research funding to the SUS; (3) SAGE enhances communication and grants Florida SUS experts more visibility, making universities more marketable; and (4) SAGE combines and unifies existing data from multiple sources into one user Web-accessible interface.

Ideally the aggregated data would be accessible from one point of entry. For example, the data being accessed may consist of multiple data types that have been converted to a standard file format. SAGE consists of the typical university-sponsored research data incremented by object-oriented data such as research topic, investigator name, funding agency, or university. One of SAGE's advantages is that there is only one point of entry or a Web-enabled interface, allowing multiple occurrences of the interface and giving the end user deployment flexibility. The main interfaces on the query engine (in SAGE) use text fields to search the processed data for key words, fields of expertise, names, or other applicable search fields. The application processes the end user's query and returns the pertinent information. The information is collected from a conglomeration of multimedia databases and then presented as queried (see the figure).

Key accomplishments (1998):

- The development of the SAGE database involved an initial design followed by the incremental implementation phases:
  - The initial design phase constituted a comprehensive survey of available tools and methodologies. An assessment was carried out to select the most efficient approach to data storage and data retrieval. A middleware development environment was selected because of its significant application strengths and demonstrated database interaction capabilities. Additionally, it provided the ability for secure transactions.
  - The implementation phase of SAGE involved the design of the middleware modules, each with an assigned task. Querying modules were used to provide search capabilities. Each query interface involved several modules that interacted with the database.
  - A sample database was obtained from the Florida International University (FIU) Division



SAGE Architecture

of Sponsored Research and Training (DSRT) to provide a prototype data storage structure. After applying an extraction algorithm to the data, the SAGE database was populated with FIU data.

- The SAGE application was then Web-enabled on the primary server for its current wave of beta testing.
- The SAGE prototype was then populated with the University of Central Florida DSRT database. Some of the technical challenges faced during the design and implementation of this project included the fact that databases from Florida SUS DSRT offices were dissimilar in design and file format and in duplicate data occurrences, field names, and stored architecture. PERL scripts were used to solve the database disparities, and a data dictionary was implemented to eliminate redundancies.

Key milestones (1999):

- Migration to a relational database structure is currently underway. This is a necessary step because of its efficiency and scalability with data. The middleware source is currently being recoded to take advantage of the improved data structures. This new relational architecture will also alleviate the data inconsistency problem across SUS platforms.
- Population of the SAGE database with each of the remaining SUS DSRT databases.

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Participating Organization: Florida International University (I. Becerra-Fernandez)

Process Analysis and Modeling: Statistical Process Control Techniques for Variable Shuttle System Performance Data

NASA Shuttle Processing has shifted to an insight focus requiring the use of statistical techniques for analyzing system performance data to evaluate Certification of Flight Readiness (COFR), to determine requirements for enhancement / upgrades, and to evaluate contractor performance. Several case studies were developed to demonstrate the application of statistical techniques to assist in the insight role. Case studies completed during this project analyzed Space Shuttle system performance data engineers identified as critical variables indicating the health of the associated system (see the table). The analyses provided information that could be used to determine if there is evidence to support the need for a system enhancement / modification.

One of the studies supporting an enhancement was the potable water case study. Water is a key ingredient to a successful Shuttle mission. Water storage space aboard the orbiter is limited to four potable water tanks with a usable capacity of 165 pounds. Astronauts also use water generated as a byproduct of the electrical generation system when hydrogen and oxygen are combined in the orbiter's fuel cells. The water produced by the fuel cells is stored in the potable water tanks for use during flight. It is important to ensure the quality of the water is satisfactory for human consumption. To monitor the quality of the water, the nickel concentration is measured. Analysis of the nickel concentration requires monitoring the stability of the nickel concentration for each vehicle. To monitor the stability of the nickel concentration, Individual X and Moving Range charts were constructed for each vehicle at 15 (L-15) and 3 (L-3) days prior to launch. In the case of Atlantis (OV-104), the Moving Range chart indicated a stable process, while the Individual X chart demonstrated a statistically significant pattern indicating that the nickel concentrations have increased significantly beginning with STS-66. Research shows this coincided with an extended maintenance period at Palmdale, California.

Prior to using the statistical analysis tools, system engineers plotted the nickel level versus the mission. The resultant charts made it appear there may have been a worsening nickel level. This case study, however, showed the process to be stable after the initial step function increase was noticed. If statistical quality control techniques had been used, systems engineers would have reconsidered the conclusion to remove and replace the existing chilled heat exchanger because of the "apparent" continuing increase in the nickel level.

Key accomplishments:

- 1994: Completion of variable-form data collection and analysis on two Thermal Protection System processes.
- 1995: Collaboration with USBI for analysis and improvement of solid rocket booster processes. An orbiter structural bonding process improvement effort was initiated.
- 1996: Phase II of the structured experimentation supporting the orbiter structural bonding process improvement was completed.
- 1997: Held a series of three workshops for NASA and contractor engineers to develop skills in collecting, analyzing, and interpreting results from variable-form data.
- 1998: Case studies depicting the application of statistical techniques to evaluate COFR and determine requirements for enhancements / upgrades were developed.

Key milestones:

- 1999: Implementation of statistical techniques supporting process analysis throughout Shuttle Processing. Implementation of process improvements recommended through the case studies and measurement of the effectiveness of process changes. Investigate potential technology transfer / synergy to the Orbiter Reliability-Centered Maintenance effort, Checkout, Launch and

Control System project, and Integrated Vehicle Health Monitoring. Investigation of key characteristic methodologies for selecting system performance parameters on which to apply statistical process control techniques.

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Participating Organizations: Embry-Riddle Aeronautical University (D. Osborne), NASA/KSC Shuttle Processing (S. Minute, V. Elentri, T. Draus, H. Johnson, S. Greenwell, C. Estrada, C. Mariano, and F. Jones), Boeing (T. Damoff), United Space Alliance, and University of Central Florida (Y. Hosni and R. Safford)

Case Studies Demonstrating the Application of Statistical Techniques

Orbiter System	Data and Subsystem Studied
Thermal Protection System	Nose landing gear door corner laser step and gap measurements Orbiter processing facility dewpoint temperature measurement
Orbiter Structures	Bond pull tests
Guidance, Navigation, and Control System	ADTA / AADT test set transducer data from air data system
Main Propulsion System	LH_2, LO_2, GH_2, GO_2, and helium subsystem data
Orbiter Maneuvering System / Reaction Control System	OMS / RCS helium isolation valve data from the helium pressurization subsystem Primary RCS regulator data from the helium pressurization subsystem
Environmental Control and Life Support System	Nickel concentration data from the supply and waste water management system
Orbiter Mechanisms	Extension times from the landing gear subsystem Orbiter / ET umbilical bolt ultrasonic measurement data from the orbiter / external tank separation system

Process Analysis and Modeling: Intelligent Assistant for Optimization Modeling

Over the last 40 years, the versatility of optimization modeling has established it as a popular decisionmaking aid. Optimization encompasses a suite of powerful decision support paradigms that enable the modeling of any decisionmaking environment in terms of objectives, decisions influencing the objectives, and constraints binding the decisions. However, the potential of these powerful techniques has remained largely unharnessed due to the following inherent difficulties in constructing optimization models:

1. Optimization models typically address aspects of the domain that are often hidden or invisible to casual observers.

2. Highly specialized skills are required to design and generate executable models.

3. Optimization-based decision support systems typically depend on building custom solutions for different domain situations.

4. There are few available tools able to leverage the expertise of domain experts.

Preliminary research to alleviate these difficulties was conducted under a Phase I Small Business Innovation Research (SBIR) contract. The central product of this effort was a prototype implementation of the Optimization Modeling Assistant (OMA). Several key Phase I objectives were realized during this initial effort. The research team developed a structured method of optimization model development and created a structured, ontology-based method for knowledge acquisition and analysis. Another key objective was to develop a knowledge base of heuristics, principles, and rules that assist in optimization model development. Templates were created that encapsulated the knowledge of optimization modeling paradigms for both application-specific and generic modeling.

The Phase II technology hardening efforts identified another important factor that limits widespread application of optimization techniques to practical problems: the unavailability of much of the information needed for developing optimization models. While optimization techniques provide analytically sound solutions, their success hinges on the availability of accurate input data. Often, the input data required to develop valid optimization models does not exist or is unaccessible in most domains. Recognizing this, Knowledge Based Systems, Inc., expanded the architecture of the Phase II OMA to include simulation-based optimization. Simulation will be used to generate the necessary input data, which is then used by OMA for optimization. Using the two powerful decision support techniques together, OMA will deliver comprehensive decision support analysis capabilities to managers and decisionmakers. The enhanced OMA software implementation was completed in 1998 (see the figure).

Phase III activities planned in 1999 include (1) exercising the OMA software with KSC domain data, (2) refining the OMA for commercial applications, and (3) demonstrating the OMA on sustainment and remanufacturing applications at Tinker Air Force Base, Oklahoma City, Oklahoma, as part of another Phase II SBIR initiative.

Key accomplishments:

- 1996: Completion of the Phase I SBIR contract. Development of a prototype OMA. Selection for Phase II follow-on research.
- 1997: Defined the OMA prototype and templates. Designed OMA extensions for simulation-based optimization. Developed KSC process models for the OMA application.
- 1998: Prototyped simulation-based optimization. Completed OMA implementation. Acquired KSC domain data for the OMA application.

Key milestones:

- 1999: Complete the OMA application at KSC. Demonstrate the OMA at Tinker Air Force Base. Commercialize the OMA.

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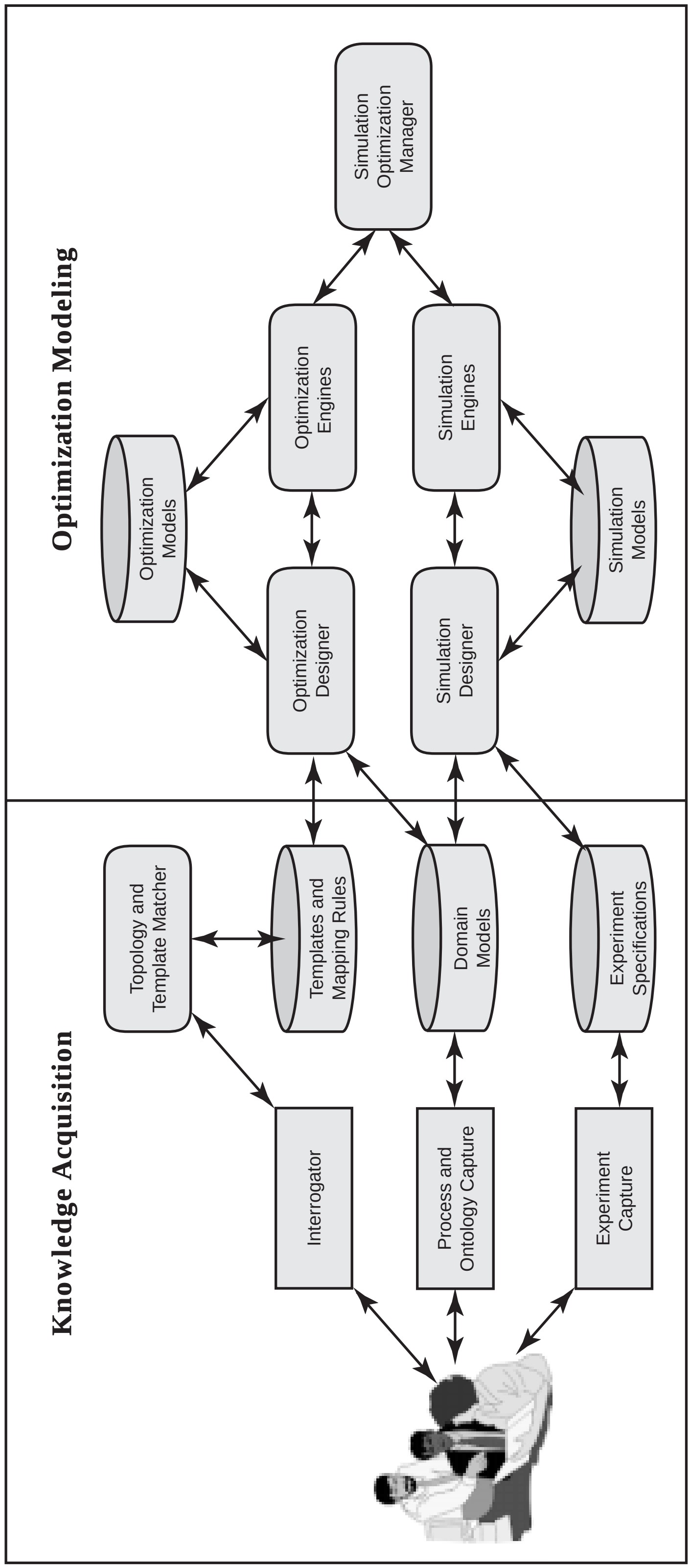
Participating Organization: Knowledge Based Systems, Inc. (Dr. P.C. Benjamin)



OMA Conceptual Architecture

Process Analysis and Modeling: Vision Spaceport Model Development

There is a need for a better understanding of the interactions that occur between flight systems and their required launch infrastructure (the spaceport). Visibility and understanding of these interactions are needed to dramatically improve the design of future launch systems with a focus on reducing the cost of access to space. A reduction in the cost can only be achieved with designs that improve life-cycle cost factors, one of the main objectives of the Vision Spaceport project. The Vision Spaceport project has a goal to develop models that allow vehicle designers to understand the effect of vehicle design parameters on spaceport operations. The required models will provide vehicle designers with critical measures of performance that define system costs (for example, single vehicle flight rate, the type and number of facilities required, and the cost of operations per flight).

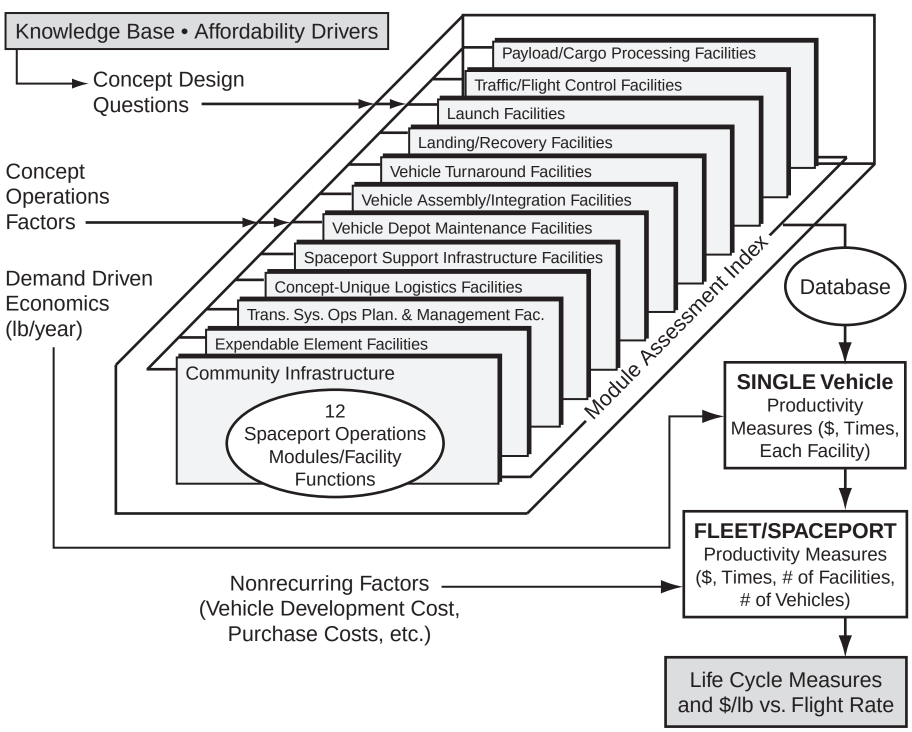


Figure 1. Spaceport Model Definition and AATe Basic Structure

During the summer of 1998, a Vision Spaceport project task developed a prototype model that combined a knowledge-based approach with existing data. The model, called the Architectural Assessment Tool - enhanced (AATe), is traceable to the national team called the Space Propulsion Synergy Team and supports NASA's Highly Reusable Space Transportation study. The tool uses a series of multiattribute utility functions to correlate concept design parameters to spaceport facility requirements. These functions capture not only the relation of a particular choice to the outputs but also the strength or importance of the broader context being addressed. In this way, the model behaves with some similarity to "real world" interactions and thus reflects cost and performance cause and effect.

The cost assessment for a vehicle concept is based on how it interacts with 12 generic spaceport operational modules (figure 1) that represent functional cost centers. Each module has a knowledge-based utility function that is calculated as the user inputs the concept vehicle (figure 2). Inputs consist of a set of

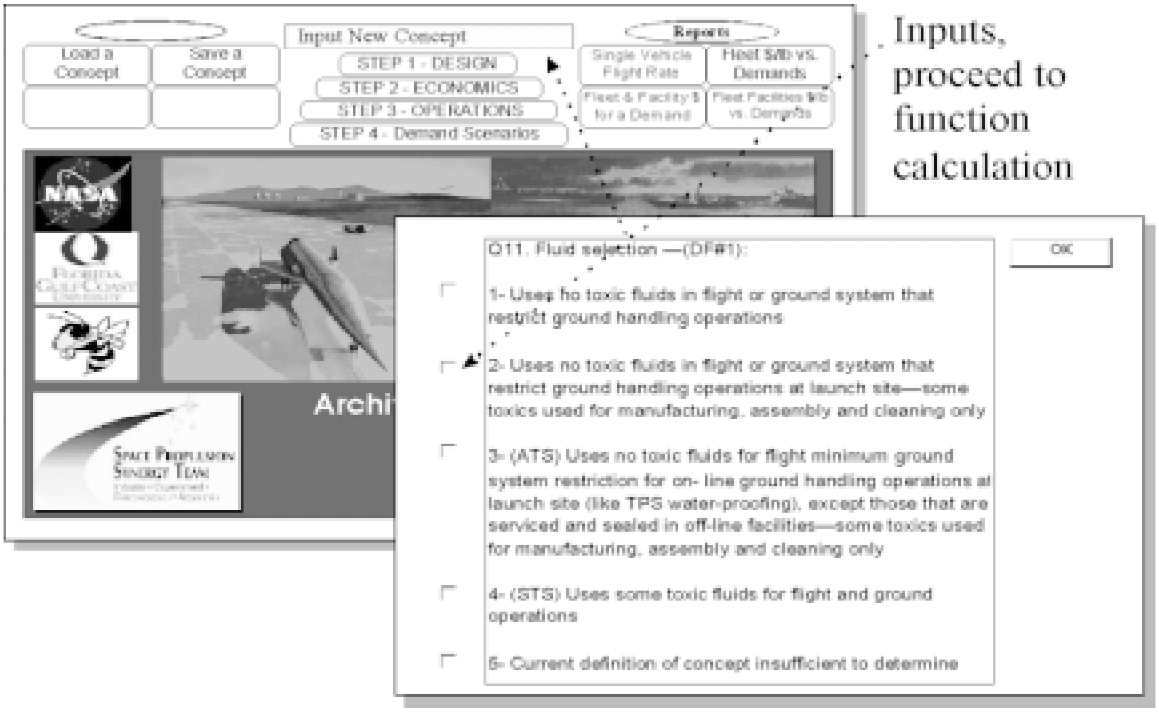


Figure 2. User Interface

questions for the concept being assessed, and these questions are based on the knowledge capture of spaceport cost drivers. The data set used to calculate the measures of performance includes a baseline (the Shuttle in this case) as well as a series of extrapolations, which are higher or lower costs and cycle times.

Key accomplishments (1998):

- Model methodologies that integrate flight architectures with the ground infrastructure (spaceport); that correlate spaceport modules to an integrated single vehicle performance (flight rate, operational cost, and investment cost); and that assess life-cycle costs for various demand scenarios.
- Software that tested all the previously mentioned methodologies.

Key milestones (1999 and 2000):

- Working product for top-level vehicle system architectures.
- Use of the tool in space launch assessments.

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Participating Organizations: Ames Research Center, Command and Control Technologies, Boeing, Lockheed Martin, United Space Alliance, University of Central Florida Center for Simulation and Training, and Florida Gulf Coast University (A.J. Ruiz-Torres)

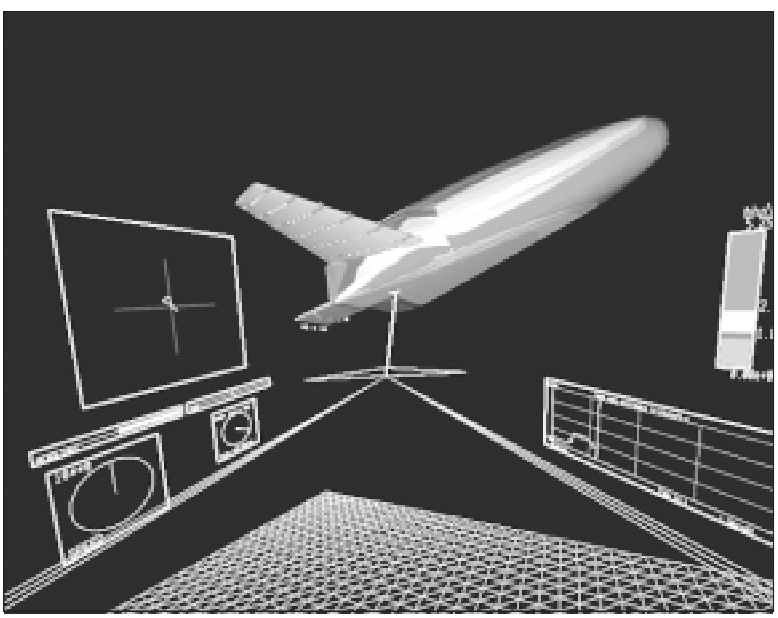
Process Analysis and Modeling: Intelligent Synthesis Environment

In recent years, NASA has been challenged to perform missions under reduced budgets and decreased timelines. NASA has also recently implemented changes in structure that reduce duplication of engineering resources throughout the Agency. Centers of Excellence have been established to focus technical expertise in response to a shrinking work force. Therefore, many engineering tasks that once could be accomplished completely within one NASA center now must be distributed among the centers to capture the necessary level of technical expertise. The distributed nature of NASA's technical expertise and the need to perform in a "faster, better, cheaper" environment have driven the Agency to develop new capabilities. At the same time, NASA has been asked to help lead U.S. companies into the 21st century through a deployment of cutting-edge systems at a level of affordability that has not been seen to this date.

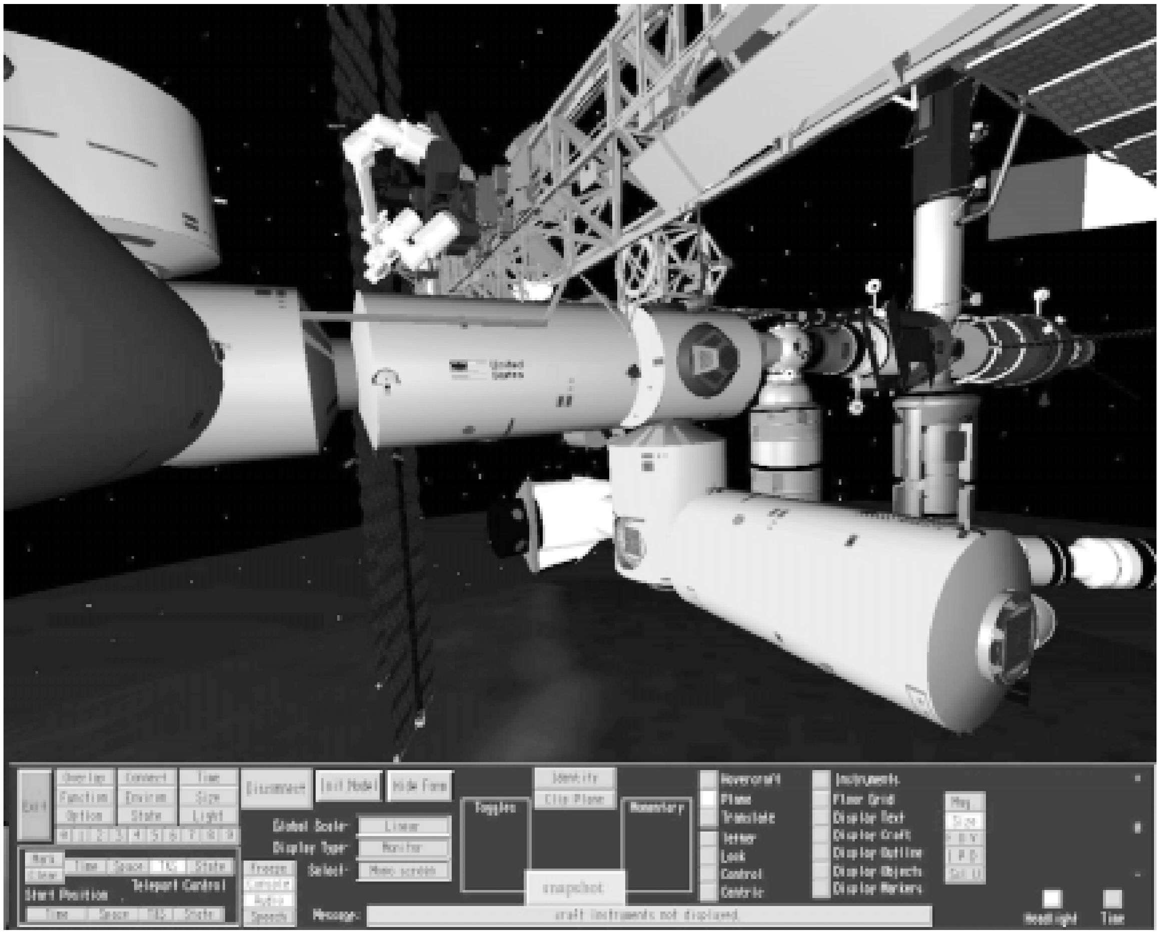
The Intelligent Synthesis Environment (ISE) program seeks to address the geographical challenges as well as help improve the engineering tools, technologies, and methodologies for NASA and U.S. industry. In general, these have not advanced significantly over the past several years. A plan is being made whereby technologies developed in the NASA research centers or their partners are deployed as prototypes across the Agency. As these become mature, contractors chosen to maintain the prototypes will be able to market them to U.S. industry. With the commercialization and subsequent reduction of the cost of these systems, it is hoped the private sector will be able to benefit from the systems engineering efforts funded by NASA.

The Agency started the process this year by deploying a Collaborative Engineering Environment (CEE) infrastructure across the Agency. Each center received one of the Core Capability Rooms with the option to buy more out of their own budgets. The Core Capability Rooms contain audio and video conferencing as well as a data conferencing capability through netmeeting. These rooms are maintained through a contractor set up to handle the Agency's needs.

In the next year, the plan is to deploy the Immersive Environment (IE) or 3-D data visualization tools as well as a data storage infrastructure to support Agency-wide reality conferencing. With these tools in place, the Agency will have the capability to develop and run systems through a complete life cycle in a synthetic environment. This will aid in the understanding of the complex issues involved in the development and deployment of space technologies without reliance on expensive physical modeling or paper analysis.



Reentry Thermal Analysis (From Langly Research Center)



International Space Station Simulation (From Langly Research Center)

In the future, NASA as well as industry and academia partners will develop new tools and methodologies that address the flow of information from initial concept through manufacturing.

Key accomplishments:

- 1998: The NASA ISE Team was formed; the initial kickoff meeting was held; and the initial collaborative infrastructure was deployed.

Key milestone:

- 1999: Install IE's at all centers and a data storage infrastructure across the Agency.

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Process Analysis and Modeling: Virtual Shuttle Processing Model

The Virtual Shuttle Processing (VSP) Collaborative Engineering Environment (CEE) project is developing new engineering tools and capabilities at KSC. The new technologies allow engineers to bring their efforts to the next level of excellence and standardize their use across all NASA centers.

Level 1 consists of basic data conferencing and is being provided through ODIN for KSC desktops and some conference rooms. Level 2 consists of audio, video, and data conferencing. Level 3 adds the immersive environment and reality conferencing capability to the audio, video, and data conferencing.

The VSP model is being developed to enhance engineering design, improve processing, and enhance technical training. Maintenance of the Shuttle orbiter in its processing facility is being modeled.

Key accomplishments:

- 1998: Project initiation. Delivery of Level 1 and Level 2 CEE capabilities.

Key milestone:

- 1999 and beyond: Delivery of Level 3 CEE capabilities and multiple applications.

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Participating Organizations: United Space Alliance, Boeing Aerospace, and NASA/Ames

Automation and Robotics

The Automation and Robotics program at the John F. Kennedy Space Center (KSC) is focused on advanced development cutting-edge technologies to enhance KSC's core mission of launch and landing ground operations. The program also provides a partnering with other NASA research centers to demonstrate advanced mobile base ground processing technologies for problems that must be addressed and solved for future space missions, such as remote autonomous Mars operations. In this role, KSC is developing state-of-the-art technologies in sensors, mechanisms, manipulators, and mobile bases for ground operations that can be applied to future NASA mission scenarios. This field testing has selected space mission technologies that are also applicable to ground processing applications and problem areas. KSC provides the opportunity to take these technologies out of the laboratory and apply them to actual ground operations at KSC. Technologies addressed in this section include advanced cable inspection capabilities, improved data collection and intuitive graphical user interfaces, and automation of large mechanical load-carrying devices.

Technology areas that KSC is working to develop and apply include: integration of real-time controls with advanced information systems, obstacle-avoidance sensors and systems, multidegree-of-freedom robotic devices and systems, intelligent control systems, imbedded and distributed controls, inspection sensors and systems, integration of advanced software technologies in control and sensor interpretation, and model- and rule-based systems for health monitoring and diagnosis. All these technologies can be applied to automating ground processing tasks.

Application areas that are currently being addressed in this year's report include the Solid Rocket Motor Stacking Enhancement Tool, Automated Ground Umbilicals, and the Cable Line Inspection Mechanism.

Advanced Life Support Automated Remote Manipulator (ALSARM)

The objective of the ALSARM project is to develop a prototype system to take environmental measurements inside the Biomass Production Chamber (BPC) breadboard project (also known as the Controlled Ecological Life Support System or CELSS) at KSC. The BPC is operated by the Advanced Life Support project office (JJ-G). The ALSARM is performed in conjunction with the University of Central Florida (UCF). A two-semester design course at UCF resulted in several concepts for the ALSARM. KSC and UCF decided on a final concept that meets all the system and BPC requirements. The project is complete and operational. Phase II of the ALSARM project (development of an end-effector to take plant samples remotely) will begin in late 1998.

The BPC consists of two separate levels used to grow crops in an almost totally enclosed environment. The BPC will help NASA understand how to grow crops in space for Moon or Mars bases. During the course of study, technicians have to enter the chamber to measure environmental parameters such as air temperature, infrared temperature, relative humidity, air velocity, and light intensity. Entry of personnel into the BPC disturbs the environment in several ways. The opening of the chamber door accounts for about half the chamber daily leak rate. The technicians contaminate the environment by their respiration, which expels carbon dioxide and organic products. The mere presence of technicians can modify the air flow patterns in the BPC. The environmental measurements, which take about an hour, are performed serially. Also, it is difficult for people to take measurements at exactly the same points from one type of measurement to another or from one test to another. The ALSARM will be an automated method of taking these measurements that will eliminate personnel entry, reduce the chamber leak rate, and allow more consistent measurements.

ALSARM in the BPC

The ALSARM integrates state-of-the-art systems in control, mobility, manipulation, information management, and sensor technologies to perform the BPC environmental measurements. The system will be expanded to include an end-effector (or tool) on the manipulator to take plant samples and eventually perform other functions such as planting and harvesting. This end-effector will be developed during Phase II of the ALSARM project that started in August 1998.

Key design features of the ALSARM include: (1) automated control via a tether cable, (2) a 3-degree-of-freedom robot manipulator, (3) multiple sensor array, (4) interfaces to existing NASA databases, and (5) development of an end-effector for plant sampling.

The accomplishments for 1998 include completion of operational testing at the BPC, fabrication of a replacement sensor array, startup of Phase II (end-effector), and development of a preliminary end-effector design.

Completion of the preliminary end-effector design and fabrication of the replacement sensor array were the major efforts for the remainder of 1998.

Key accomplishments and milestones:

- August 1993: Project initiated and concept designs evaluated.
- June 1994: Final report and design concept completed.
- October 1994: Systems requirements review completed.
- October 1994: 30% design review.
- November 1994: 60% design review.
- November 1994: 90% design review.
- December 1994: Final review.
- March 1995: Redesign of horizontal telescoping arm started.
- August 1995: Redesign of horizontal telescoping arm finished.
- October 1997: Fabrication of the ALSARM complete.
- December 1997: Laboratory testing of the ALSARM complete.
- July 1997: Installation of the ALSARM into the BPC.
- August 1997 to January 1998: Activation and validation testing of the ALSARM.
- January to August 1998: Development and fabrication of a replacement end-effector.
- Late 1998: Development of the ALSARM end-effector.

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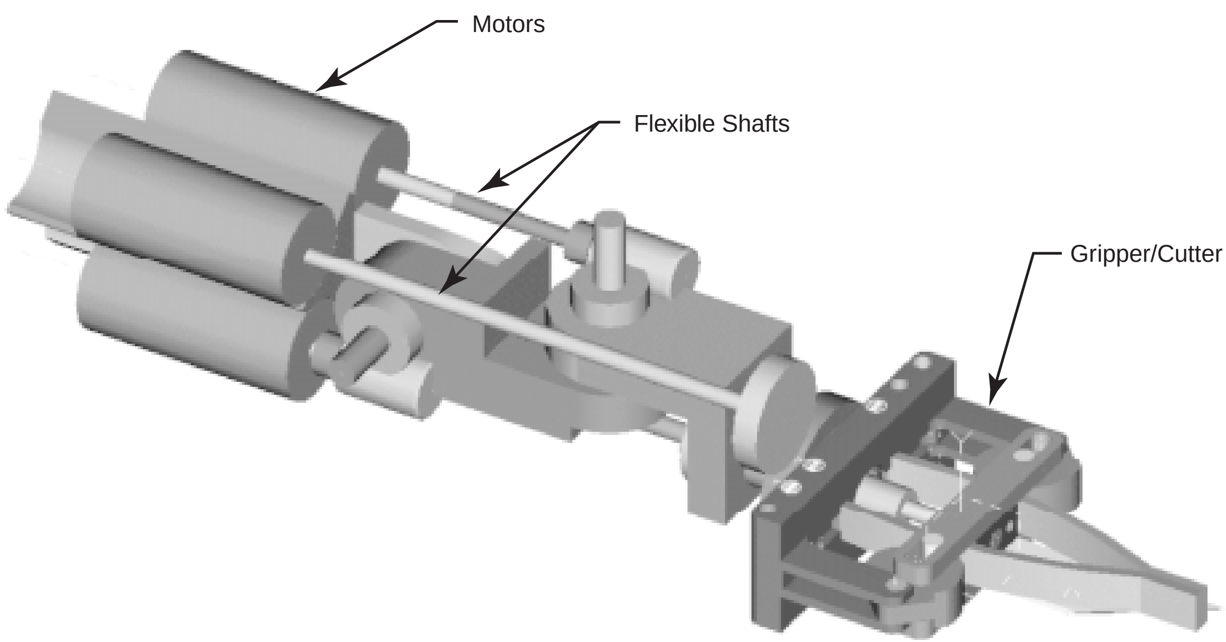
Participating Organization: University of Central Florida (Dr. R. Johnson)



ALSARM End-Effector Preliminary Design

Advanced Payload Transfer Measurement System (APTMS)

The objective of this project is to develop a simple, robust, centrally operated, and portable system to automatically measure Xo, Yo, and Zo offsets between the trunnions and their support during payload transfer operations in the Vertical Processing Facility, Orbiter Processing Facility, Operations and Checkout Building, and Payload Changeout Room. Each trunnion will be instrumented and the misalignment will be displayed to the move conductor. Future expansion capabilities include fast calculation of the next move command and closed-loop control of the operation. Key design features of the APTMS include:

- Quick Xo, Yo, and Zo measurement and display of data to move the conductor
- Small and portable transducer
- Versatile design for use at the Vertical Processing Facility, Orbiter Processing Facility, Operations and Checkout Building, and Payload Changeout Room
- Off-the-shelf optical encoders for angle measurement
- Laptop computer for ease of portable data analysis and display
- Wireless port connection between a laptop and data acquisition system
- Programming capability to calculate the next move command
- First step for payload transfer automation at the Vertical Processing Facility and Payload Changeout Room

Benefits of the APTMS include:

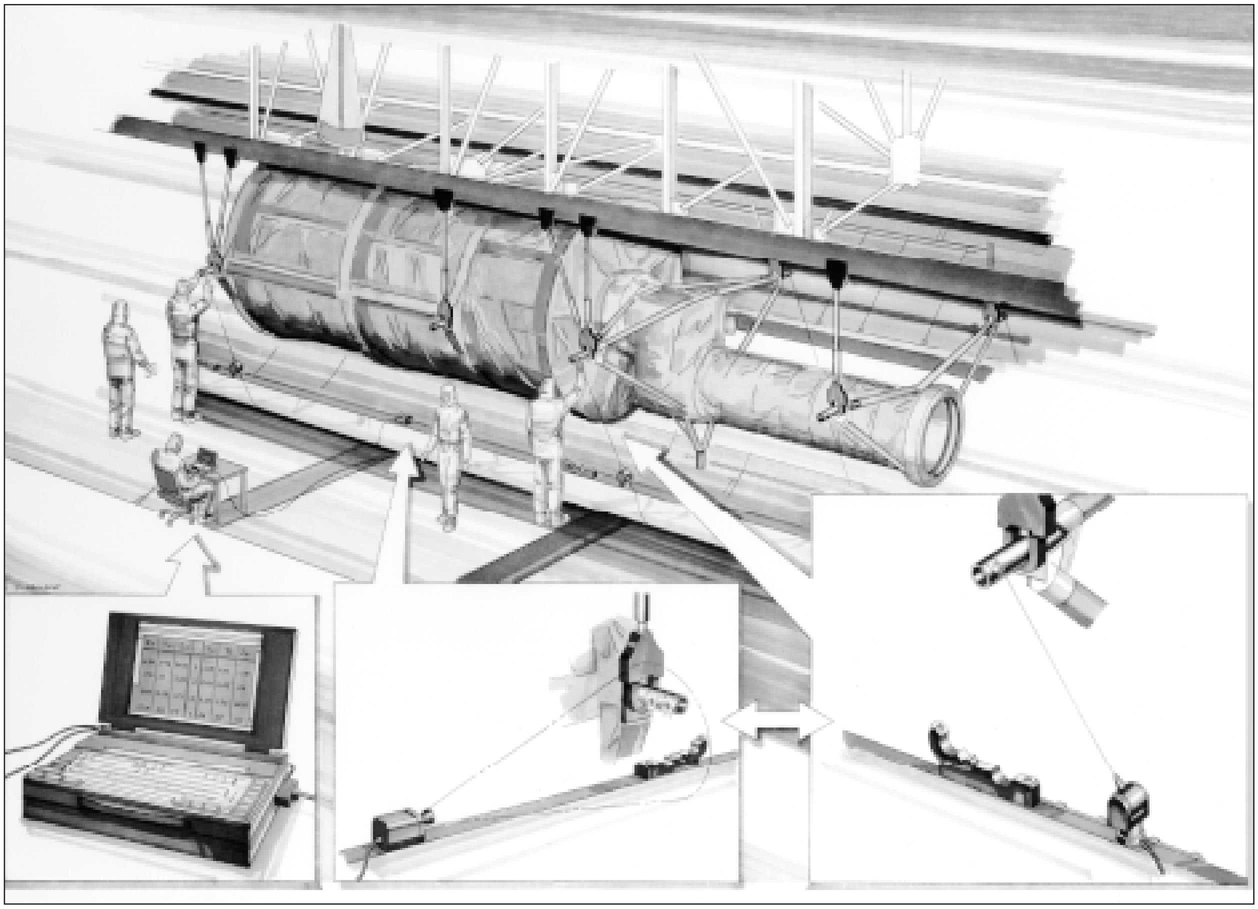
- Capability enhancements
- Reduction of time and cost for payload transfer
- Increase in measurement accuracy and reliability; reduction of error opportunities
- Increase in payload and technician safety
- Avenue for payload transfer automation of four different locations

Commercial applications of the APTMS include:

- Crane operations
- Construction
- Assembly
- Manufacturing
- Automotive
- Aerospace

Key accomplishments and milestones:

- Mechanical, electrical, and software system testing has been completed. Further adjustments are in work to meet the positioning requirements of 0.05 inch at a 6-inch range.
- 1995: Developed prototype unit.



APTMS in Operation

- 1996: Tested prototype unit and made modifications.
- 1997: Started development of production unit, design, and fabrication.
- 1998: Completed production unit and tested and implemented modifications to enhance accuracy and ease of calibration. Developed a demonstration simulation tool for presentation to customers.

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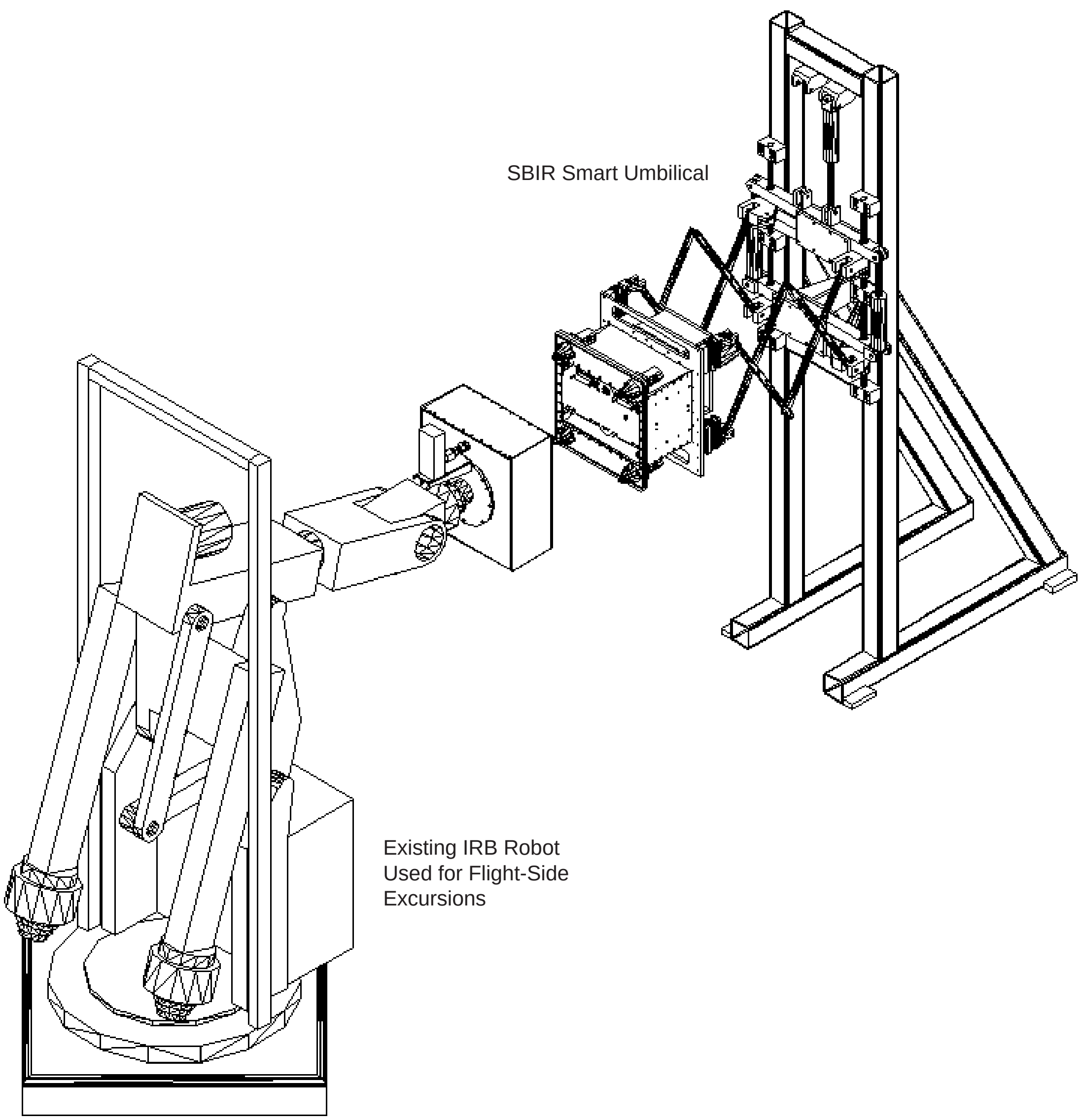
Automated Umbilical Mating Technology

Numerous launch vehicles, planetary systems, and rovers require umbilical mating for fluid flow and electrical connections. Simple, reliable, autonomous mating is required to make certain missions and systems feasible (i.e., Mars methane fueled rovers) and to provide low-cost, safe launch operations. The environment for mating (temperature, humidity, dust, cost, weight, and power) varies drastically from system to system. However, a common core technology and numerous sensor and mating techniques are needed to provide low-cost, common solutions for all systems. The technical approach involves the following:

- Development of a smart umbilical with a reconnect capability (This project will leverage off an existing Small Business Innovation Research (SBIR) project and additional available hardware.)
- Autonomous or remote operations using vision systems, force feedback, miniaturized gas detection, and state-of-the-art real-time control
- Umbilical that provides the capability to connect, disconnect, and reconnect during any point in the launch countdown process
- Investigation of various sensor and mechanism concepts for different mating environments



The benefits to NASA missions involve the following:

- Autonomous methane-fueled Mars exploration rovers (required for Mars sample return)
- Capability to connect, disconnect, and reconnect during any point in the countdown process for the Reuseable Launch Vehicle (RLV), Liquid Flyback Booster (LFBB), and Evolved Expendable Launch Vehicle (EELV) (Low-cost, high-reliability autonomous mating will enhance all future launch vehicles.)
- Cheaper, safer launch operations
- Increased launch reliability

Currently, a Phase II SBIR project is investigating and developing a highly reliable, safe, and smart automated ground/flight umbilical carrier plate for remote installation and removal. The umbilical plate will contain multiple service connections for cryogenic propellants, pneumatics (gaseous nitrogen and gaseous hydrogen), environmental control gases, and electrical power and data. The umbilical will have the ability to mate, demate, and remate with little or no human intervention. Flight side and ground side will be demonstrated with dynamic excursions based on real-world data.

The smart umbilical mating system will provide for two fluid connections and four electrical connections. After the operator manually drives the umbilical to within its alignment area, the vision control system will take over and drive the umbilical to mate with the flight-side plate. The operator has the option to give the final permission to perform each step in the mating process and can interrupt the mating process at any time. When the mating process is interrupted, the umbilical will return to the previous safe step in the mating process or will return to the home position, depending on how it is interrupted.

After the umbilical plate has been connected and latched to the flight-side plate, the umbilical system goes into a passive mode, whereby it follows the excursions of the flight side. Then the electrical and fluid connections are verified for leaks and connectivity.

The operators will access system controls through the software loaded into the control console computer. From this console, the operator will have control of and feedback from the entire system as well as the camera view of the vision system. All data acquisition hardware is also interfaced to this industrial computer. Additional design requirements include:

- Compliant self-aligning ground-side carrier plate
- Traceability to a nonsingle point failure design
- Real-world dynamic and static vehicle excursions
- Quick and reliable remote verification of interface integrity
- IRB 90 robotic arm to mimic vehicle excursions

Key accomplishments and milestones:

- June 1998: Completion of the SBIR mechanical design.
- October 1998: Completion of the SBIR electrical design.
- 1999: Completion of the SBIR automated umbilical and test and modify to provide full automation capability.

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Payload Ground Handling Mechanism (PGHM) Automation

The PGHM is located in the Payload Changeout Rooms of Space Shuttle Launch Pads A and B at KSC. The PGHM is used to remove or insert the Shuttle payload from both the orbiter payload bay and the payload transport canister. The PGHM provides the capability to load / access payloads when the vehicle is at the launch pad. Upgrades to PGHM systems are required to provide United Space Alliance operations personnel the capability to process vertical payloads in a safer and more efficient environment. The PGHM consists of the following mechanisms:

- Power X: coarse vertical motion
- Power X Stop Nut: redundant safety feature of Power X
- Power Y: coarse side-to-side motion
- Payload Support Beam X (PLSB X): fine vertical motion
- Payload Support Beam Z (PLSB Z): fine insert and retract motion
- Stem Strain: PGHM weight distribution stability
- J-Hooks: X, Y, and Z: very fine motion

The current PGHM design uses pneumatics and manpower for axis actuation. Through automation, position feedback circuits, and the elimination of hazardous manual drive systems, the proposed upgrades will provide a safer, more efficient processing environment. The project scope will be divided into two major efforts:

1. Automated Control of Mechanisms. The Power X, Power X Stop Nut, Power Y, Payload Support Beam X, Payload Support Beam Z, and Stem Strain mechanisms will be automated using commercial off-the-shelf electronic control systems. Numerous hardware-critical failure points and human-intervention-dependent operations will be eliminated. A centralized control console with a graphical user interface will be provided for the PGHM Move Director to command operations. The main objectives are to:

   - Eliminate the hardware single failure points.
   - Eliminate the operations in which human error could cause hardware damage or human injury.
   - Provide better control and feedback to the payload Move Director and technicians.
   - Increase the operational efficiency and reduce the number of personnel required for payload transfer.

2. J-Hook and Orbiter-to-Payload Position Measurement Study. J-hook and orbiter-to- payload position measurement requirements will be detailed and the system design approach will be determined in a study.

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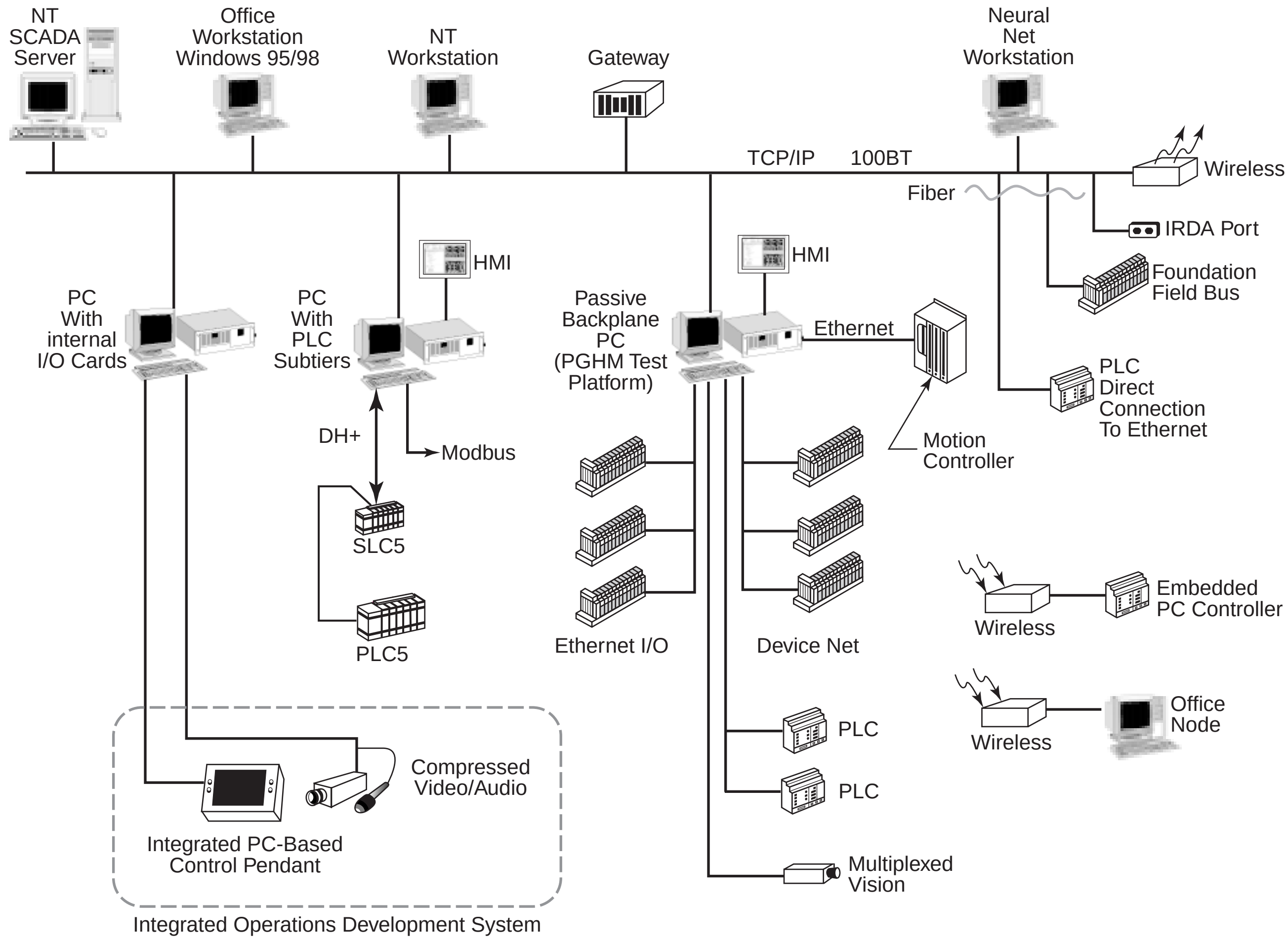
Participating Organizations: United Space Alliance and Dynacs Engineering Co., Inc.


NT
SCADA
Server
Office
Workstation
Windows 95/98
NT
Workstation
Gateway
Neural
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Workstation
TCP/IP
100BT
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Fiber
IRDA Port
Foundation
Field Bus
HMI
HMI
PC
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internal
I/O Cards
PC
With
PLC
Subtiers
Passive
Backplane
PC
(PGHM Test
Platform)
Ethernet
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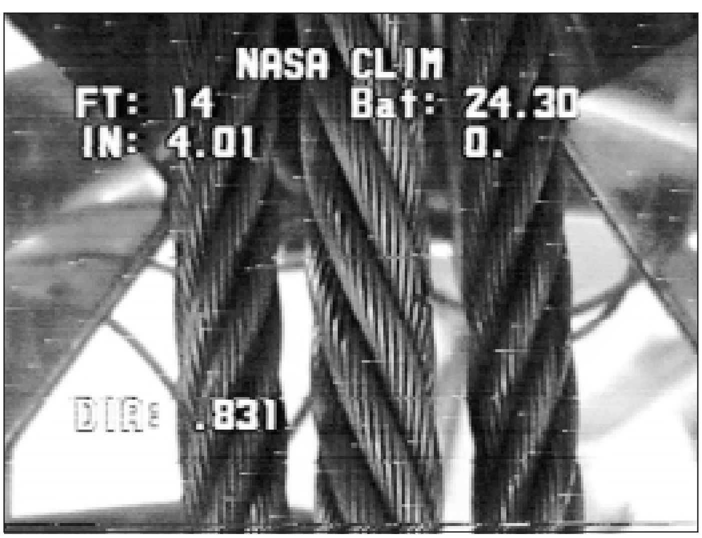
Direct
Connection
To Ethernet
DH+
Modbus
Motion
Controller
SLC5
PLC5
Ethernet I/O
Device Net
Wireless
Embedded
PC Controller
Wireless
Office
Node
PLC
PLC
Compressed
Video/Audio
Integrated PC-Based
Control Pendant
Multiplexed
Vision
Integrated Operations Development System

Cable and Line Inspection Mechanism (CLIM)

Biannual inspections of the seven slide-wire cables used in the Emergency Egress System at both Launch Pads A and B require inspection crews to visually verify the integrity of the cable as the crews are lowered down the cable in the slide-wire baskets. Due to the type of cable used as slide-wires (i.e., stainless steel), magnetic resonant devices normally employed to inspect cables are inadequate. This man-intensive and time-consuming operation prompted a request to the Automated Ground Support Systems Laboratory to develop a stand-alone system for automated cable inspection. In addition, no method exists for inspection of the lightning cables at each launch pad due to their inaccessibility.

The cable failures to be identified by the automated system, per the applicable Operations and Maintenance Requirements Document (OMRS File IV), are characterized by frayed strands, bird nesting, stretching, and corrosion. The cable undergoes load testing on a periodic basis and is man rated by weighting the egress baskets with sandbags and sending them down the cable. Consequently, this is not a task for the automated system. The inspection teams rely on a visual inspection of the surface of the cables with a cursory check of the cable diameter using a go/no-go gage every 10 feet. The targeted cables were identified to have an inclination of no more than 45 degrees, a length of approximately 1,200 feet, and a diameter of 1/2 to 3/4 inch. Finally, a prototype unit had already been developed for the project but required testing. A production unit based on the prototype design was needed.

control scheme using a radio frequency control system for radio-controlled airplanes was employed. A method of measuring the cable diameter was found. Finally, a microcomputer to control the unit was used. Due to the limited accessibility to power over the distances involved, the unit operates on batteries.



CLIM Cable Video

The prototype unit was tested on 300 feet of guy wire supporting the 500-foot weather tower north of the Vehicle Assembly Building. The guy wire was 3/4 inch thick and at an inclination of 15 degrees. The unit was operated on the cable until the distances required for the slide-wire inspections were obtained. The data captured from the test was graphed for demonstration. Problems were identified and alternate equipment was chosen. Currently, the manufacture of a production unit is in process for use by the customer. A 75-percent drawing package has been released.

Key accomplishments:

- 1997: Identified customer requirements.
- 1998: Tested the prototype unit. Manufactured the production unit.

Key milestone:

- 1999: Assemble, test, and turn over the production unit.

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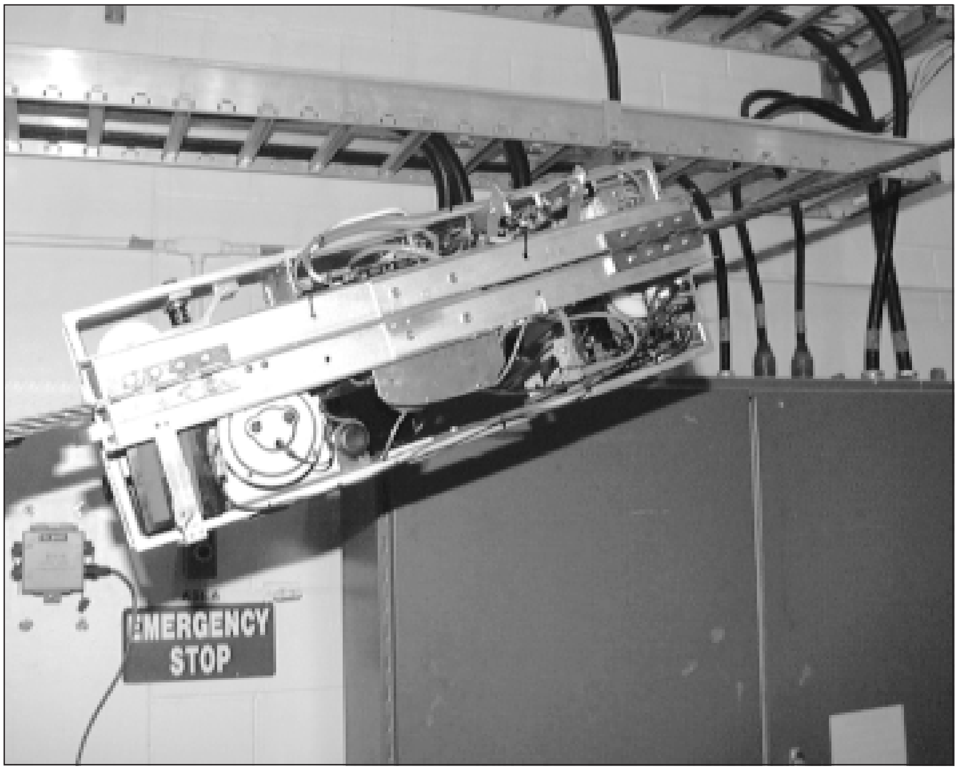
Participating Organizations: NASA MM-G3 (R. Morrison, J. Bonner, and M. Hogue), NASA PK-J (K. Nowak), NASA MM-E (J. Richards-Gruendel and L. Parrish), and United Space Alliance (G. Hajdaj and M. Olka)



Prototype Unit on the Test Cable

Launch Pad Tower View of the Slide Wires

OmniBot Mobile Base

The objective of the OmniBot project is to develop a hazardous duty mobile base as an advanced development test bed to research alternate technical approaches for remotely controlled operations in hazardous areas. In addition, this base will be used to test various automated umbilical technologies for autonomous mobile vehicles. In hazardous environments where it is too dangerous to send in unprotected personnel, a mobile base could be used to perform remote inspections, site surveys, and operations.

The OmniBot is driven with four brushless servomotors connected to omnidirectional wheels (Mechanum). This allows for complete 2-degree-of-freedom motion, which results in extremely high maneuverability. The benefit of this motion profile can truly be appreciated when the vehicle is operated in a teleoperational mode.

Currently the vehicle can be controlled with a radio frequency (RF) control box or with a hardwired joystick. With the video transmission gear installed, teleoperation is possible up to a distance of 1,800 feet.

The next phase in the project is the construction of an operator's control station, a sensor package, and manipulator systems.

Key accomplishments and milestones:

- January 1997: Construction of the motion base.
- June 1997: Testing of the motion base and control system.
- March 1998: Construction of the RF control system.
- August 1998: Selection / procurement of the multi-tasking system.
- September 1998: Installation of the video RF gear.

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OmniBot Mobile Base

Closeup of Omni (Mechanum) Wheels

Electro-Mechanical Actuator

The objective of the Electro-Mechanical Actuator (EMA) project is to evaluate and demonstrate the viability of electro-mechanical actuators to replace pneumatic actuation for use in launch processing ground support equipment (GSE) at KSC. The current pneumatic actuation systems, such as the cryogenic fuel and oxidizer systems, firex systems, sound suppression system, etc., require high maintenance and the components are becoming old and obsolete. These systems are located at the launch pads and are exposed to the rigors of launch and the high humidity and salty seaside environment. Use of EMA's has the potential to reduce the complexity and number of components required by as much as 80 percent. Commericial off-the-shelf electro-mechanical actuators are being evaluated, and methods of providing high reliability through redundancy are being addressed. Higher position accuracy and repeatability are also potential benefits from the use of EMA's.

The EMA system consists of one electro-mechanical actuator controlled by two programmable logic controllers (PLC's) and two servo-drives in a parallel configuration for highly reliable operation. Commercial use of single-string control using PLC's and servo-drives for EMA's has proven these system components to be highly reliable, accurate, and economical. Once studied and proven for dual-control redundancy, the concept could provide the same benefits for critical systems.

Key accomplishments and milestones:

- April 1998: Design and layout of the EMA test plan.
- June 1998: Procurement and mounting of Allen Bradley PLC's and servo-drives.
- September 1998: Procurement of Class I, Division I, electro-mechanical actuators manufactured by Exlar Corporation.
- January 1999: Testing and evaluation of EMA configurations, operating characteristics, and reliability and repeatability.

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Participating Organizations: NASA Process Engineering Directorate and United Space Alliance

Solid Rocket Motor (SRM) Stacking Enhancement Tool (SSET)

The NASA Automated Ground Support Systems Lab (MM-G3) of the Engineering Development Directorate is developing the SSET, a mobile data acquisition system used to monitor the Space Shuttle solid rocket motor stacking process in the Vehicle Assembly Building (VAB) at KSC. Four SRM segments are mated together to form a solid rocket booster, with two completed boosters used for each Space Shuttle. SRM segments are attached to a four-point lifting beam, a device that can vary the load of each of its attachment points and modify the segment shape to match that of its partner. The entire assembly is then hoisted by a crane and lowered onto the SRB under construction. The segment junction points, or field joints, are critical interconnections whose failure could cause a catastrophe.

The stacking process takes many hours and is manpower intensive, so delays due to system failures are costly. The SSET replaces and combines the functions of two antiquated systems already in use, the Temposonics measurement system and the lifting beam load panel. The Temposonics measurement system is composed of four one-dimensional (1D) sensors (which are located at 90-degree intervals between the two segments) and a data acquisition computer system (used to display and record the numerical measurements). The measurements are used to determine the distance to mate, levelness, and lowering rate. The lifting beam load panel uses six strain-gage-type load cells located in the SRM lifting beam to measure the loads and levelness forces of the suspended segment. Currently, no data recording is available for the loads.

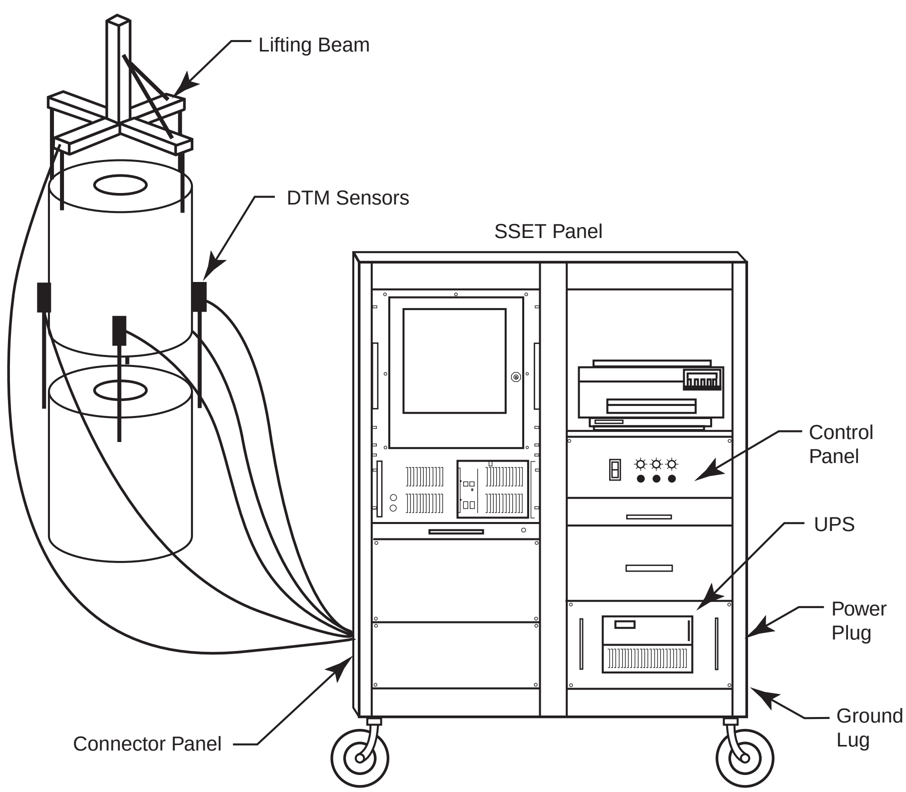

Figure 1. SRM Stacking Enhancement Tool

The SSET provides current technology data acquisition equipment to measure the existing sensors. Some benefits of the SSET are:

- A single display unit reduces the number of equipment items (figure 1).
- The information is displayed on an intuitive graphical user interface and is easy to interpret (figure 2).
- All measurement data will be recorded.
- The modular design allows for system modifications and updates.
- The onboard uninterruptible power supply (UPS) guards against data loss due to power failure.
- Advisory functions help operators maintain segment levelness.
- Built-in test ports allow for easy troubleshooting.

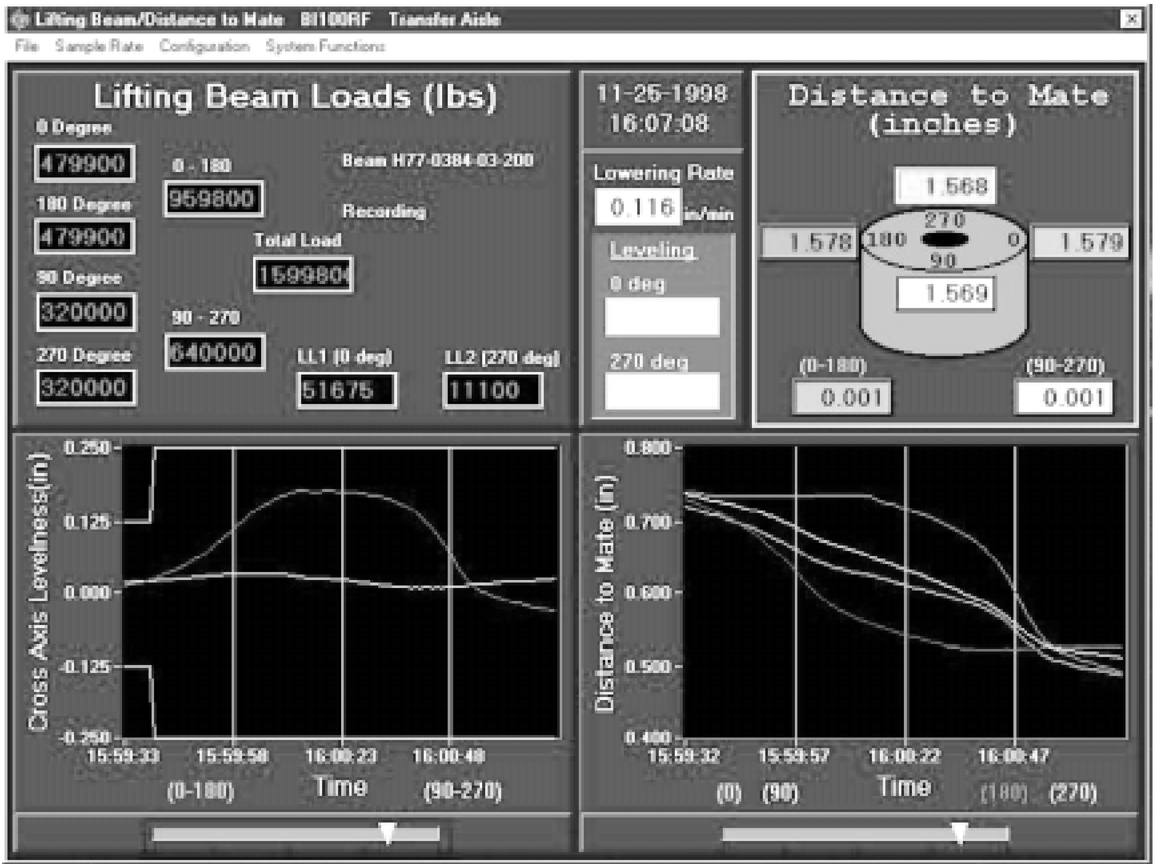

Figure 2. Graphical User Interface

- All operator events and configuration values are logged for future reference.

- Up to 1 hour of real-time data is maintained for review during stacking.

- Data review software is provided for posttest analysis.

Three production units are fabricated and undergoing certification at KSC. SSET operational readiness is scheduled for early 1999.

Key milestones:

- Completed proof-of-concept shadowing operation of an SRM stacking and destacking.
- Completed electromagnetic interference susceptibility tests.
- Completed the initial inert segment stacking operation.
- Scheduled the design certification review and operations turnover for 1999.

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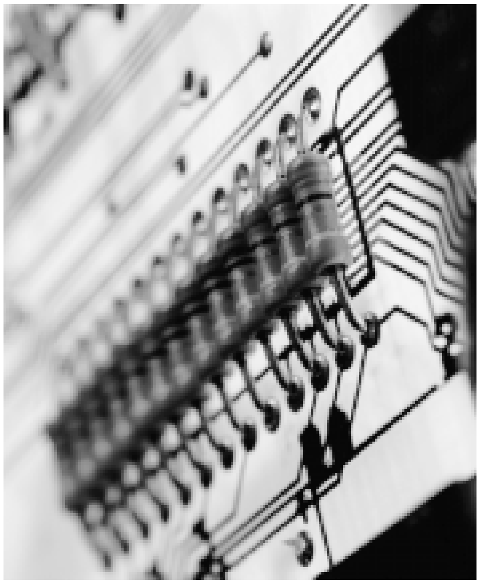
Participating Organizations: Dynacs Engineering Co., Inc., NASA PK-H, and United Space Alliance



Electronics and Instrumentation

The Electronics and Instrumentation Technology program at the John F. Kennedy Space Center (KSC) supports the development of advanced electronic technologies that enhance safety and quality, decrease launch vehicle and payload ground processing time and cost, and improve process automation. The program includes the application of applied physics and chemistry and electrical and electronic engineering, particularly in the areas of sensors, data acquisition and transmission, advanced audio systems, digital computer-controlled video, contamination and gas detection instrumentation, field inspection and nondestructive testing, and circuit monitoring instrumentation. The near-term program focuses on Space Shuttle, payloads, and Space Station ground processing enhancement by developing instruments in monitoring, testing, and vehicle processing. The long-term program is developing technology for support of future space vehicles, payloads, and launch systems by advancing the state of the art in launch vehicle and payload processing electronics and instrumentation to reduce costs and improve safety.

Space Shuttle Integrated Vehicle Health Management (IVHM) Flight Experiment

The IVHM Human Exploration and Development of Space (HEDS) Technology Demonstration (IVHM HTD) flight experiment was the first KSC designed and built payload. Its purpose was to demonstrate competing modern, off-the-shelf sensing technologies in an operational environment to make informed design decisions for the eventual orbiter upgrade IVHM. There are three objectives of IVHM:

1. More autonomous operation in flight and on the ground, which translates to reduced work load on the ground controller team. Near Earth space operations provide the luxury of having a ground team evaluate vehicle data to make real-time decisions. On a Mars mission for example, there is a 40-minute time delay to send and receive a message. Therefore, future vehicles will require more autonomous capabilities.

2. Reduced ground processing of reusable vehicles due to increased performance of system health checks in flight rather than back on the ground.

3. Enhanced vehicle safety due to the ability to monitor system health even inside the harsh environment of an engine combustion chamber as well as prediction of pending failures.

The “integrated” piece of IVHM is the total integration of flight and ground IVHM elements. The four elements of flight IVHM are advanced lightweight/low-power sensors, distributed data acquisition architecture, data processing, and mass storage. The three elements of ground IVHM are evolved control room architectures, advanced applications, and automated ground processing systems. While incorporation of an IVHM architecture into a new vehicle is a complex process in itself, implementation of IVHM into the Space Shuttle program must deal with additional considerations such as not impacting the flight manifest, cost/payback analysis, evaluation of military and commercial off-the-shelf (COTS) components, and vehicle retrofit installation considerations. The first IVHM HTD flight experiment was successfully flown on Discovery on STS-95 from October 29 to November 7, 1998. The second IVHM HTD flight experiment will re-fly all elements as well as additional sensing systems on STS-96 with a planned launch date of May 13, 1999.

During cryogenic propellant loading in the terminal launch countdown, the IVHM data stream was routed out of the orbiter’s T-0 umbilical for transmission, processing, and viewing in the Launch Control Center (LCC) via a new Ethernet network installed in the Mobile Launcher Platform, using existing fiber-optic lines connecting the launch pad with the LCC and using the new Checkout and Launch Control System (CLCS) elements. The IVHM processor autonomously began recording data at T-10 seconds prior to

Space Shuttle main engine start. Data was recorded during ascent and on-orbit during daily 1-hour snap-shot periods. The processor was dumped to the CLCS after the orbiter landed and was rolled into its Orbiter Processing Facility bay. Flight data evaluation of the first flight experiment is underway, and a preliminary assessment is that the system had 100 percent performance. The following lists contain the demonstrated technologies and the organizations responsible for their development.

IVHM HTD-1

- Micro-electromechanical systems (MEMS) hydrogen detection – LeRC, Case Western Reserve University / Makel (G. Hunter)
- Galvanic cell oxygen detection – KSC
- Main propulsion system (MPS) vacuum-jacketed (VJ) line pressure sensing – KSC
- RS485 smart sensor technology for hydrogen detection, oxygen detection, and VJ pressure – KSC
- MPS helium leak detection using thermal flow technology – KSC
- Integration / flight certification testing (thermal, vacuum, vibration, radiation, EMI, and EMC) of COTS conduction cooled VME bus architecture, flash memory, PowerPC processor, IRIG interface card, and all sensors – KSC
- Data processing software architecture (scheduler, internal health checks, and data acquisition) using VxWorks – KSC
- Ethernet ground data processing system – KSC

IVHM HTD-2

- Hydrogen detection using fiber-optic Bragg-Grating technology – LaRC and University of Maryland (K. Vipavetz)
- Structural strain and temperature determination using fiber-optic Bragg-Grating technology – Rockwell Science Center (B. Christian)
- Distributed data processing using X-33 Remote Health Node technology – Lockheed Martin, Sanders Division (R. Garbos)
- Fiber Distributed Data Interface (FDDI) technology – Hampshire Vanguard Technology Associates (T. Hardy)
- Space Shuttle Main Engine (SSME) pump vibration monitoring system with digital signal processing technology – MSFC (T. Fiorucci)

Additional information is available on the World Wide Web at: *http://www.ksc.nasa.gov/shuttle/upgrades/ksc/ivhm/data depot/ivhmhome.htm*

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Vacuum-Jacketed Line Smart Sensor

H_2 and O_2 Smart Sensors

Orbiter Jack and Leveling Operations

After landing, the orbiter is towed into the Orbiter Processing Facility (OPF) and positioned so the pair of nose landing gear (NLG) tires and each pair of main landing gear (MLG) tires are centered on a floor lift. The lift under the NLG tires raises the nose of the orbiter until the pitch of the orbiter is horizontal; then the three lifts simultaneously raise the orbiter to a specified height (the maintenance height) while maintaining the horizontal pitch. The proper maintenance height of the orbiter is critical because the surrounding facility platforms are designed for this height. Once at the maintenance height, the orbiter jacks are installed and the lifts are lowered to the ground. During a typical orbiter processing flow, the rear support of the orbiter is transferred from the aft jacks to the MLG floor lifts and then back again while the forward jacks remain attached.

These operations require a height measurement accuracy of ±1/4 inch. This is currently achieved with a set of calibrated measuring sticks to determine the height at each of the four jack attach points. The disadvantages to this measuring technique are (1) the sticks are long and thin and technicians have difficulty maintaining them vertical to the ground, (2) the distance read varies with the force the user exerts when pressing the rod against the orbiter, and (3) this technique is time consuming and uses a significant number of people. Furthermore, the long sticks are awkward to handle and there is potential for orbiter tile damage when the top of the stick is raised to vertical. Due to these difficulties, a replacement to the measuring sticks is desired.

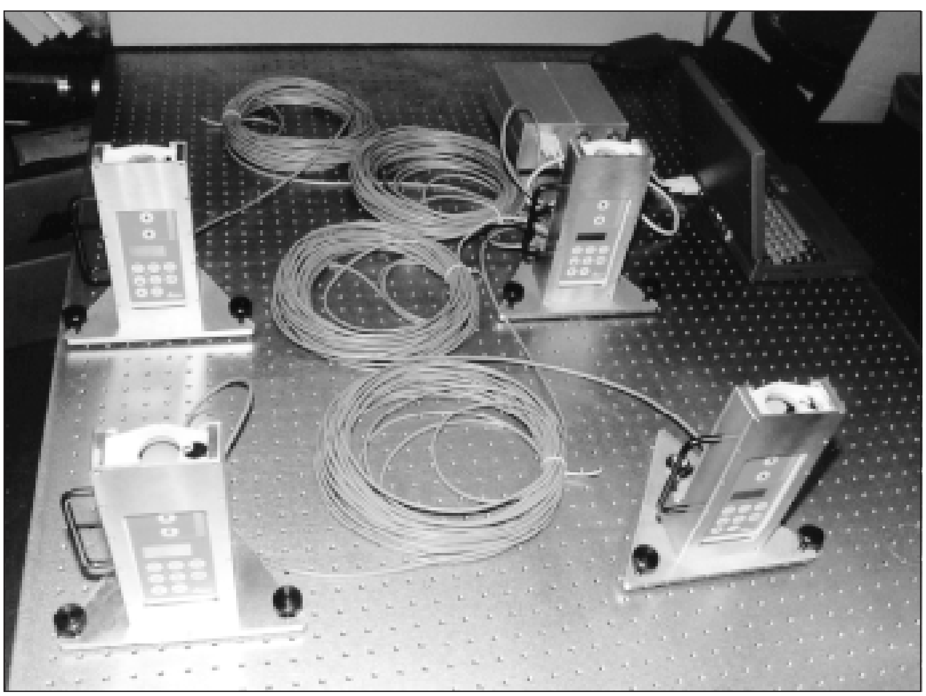

Figure 1. Four Leica Laser Rangefinders

The key to solving this problem is the use of the Leica laser rangefinder. This device allows a user to aim a laser beam at a target and read the distance to that target to within ±1/8 inch from distances between 5 and 200 feet. A system (see figure 1) was developed whereby four of these rangefinders were used, two to measure the height from the floor to the aft jack attach points and two to measure the height from the floor to the forward jack attach points. All four communicate their results to a central computer on a desk located to the left side of the orbiter midbody.

Each of the Leica units is held in a vertical orientation by an aluminum framework. The electrical connection to the Leica rangefinder provides RS-232 communication (9,600 baud) and power. The Leica rangefinder and its framework have been attached to a triangular base with a bubble level, two tilt adjustment screws, and a fixed foot. The tilt adjustment feature allows compensation for small variations in the flatness of the floor of the OPF to ensure the laser beam points near vertical.

The signals from the rangefinders are brought back to the central computer. The software was written in LabView, which allows for direct control of an

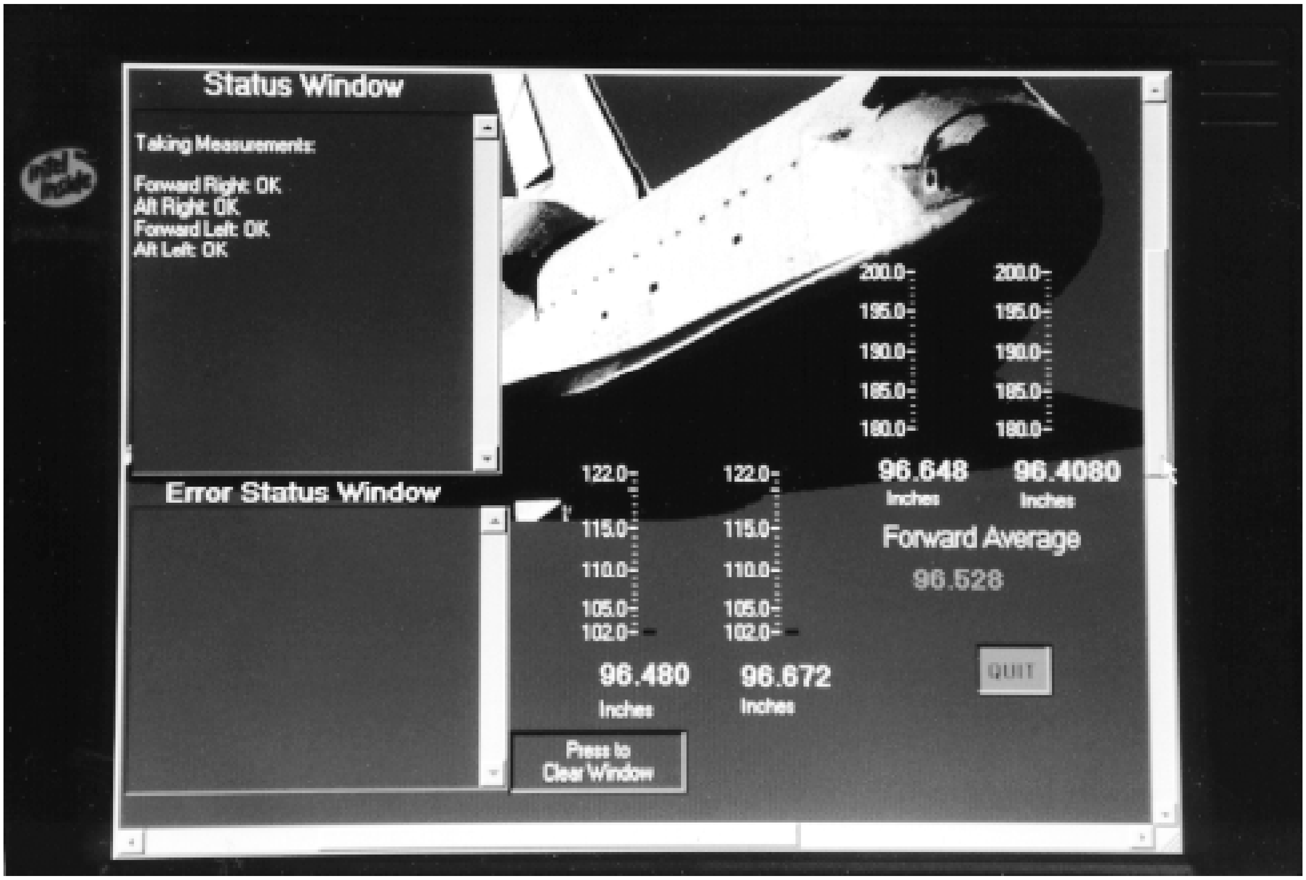

Figure 2. Computer Display of Leica Laser Rangefinder Results

RS-232 as well as the Leica rangefinders. An image of the orbiter is displayed with four bars (see figure 2; note that no bars are visible) reaching from below the orbiter up to the jack attach points. The height in inches from the floor to each jack attach point is shown and the bar is color coded to indicate the status of the measurement. Typically the bars are red if the distance is an inch or more too low, are yellow if the distance is within 1-1/4 inch too low, green if the distance is within 1/4 inch of the desired distance, and flashing red if the distance is more than 1/4 inch too high.

If a Leica rangefinder returns an error condition to the LabView software or if it does not respond at all, the software displays an error condition and counts the errors. It takes less than 3 seconds typically for all four Leica rangefinders to perform a distance measurement and for the software to receive and display these numbers. If, for some reason, the software detects a problem with a specific Leica rangefinder, it displays a "Data Drop Out" message in the error status window and does not display the distance data.

A fifth mounted Leica rangefinder with full cabling was provided as a spare. All five Leica systems were fabricated so they are within a few hundredths of an inch of each other in height and can be interchanged.

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Participating Organizations: United Space Alliance (M. McClure), PK-H (C. Davis), and Dynacs Engineering Co., Inc. (B. Burns, W.D. Haskell, T.J. Opalka, J.D. Polk, and R.C. Youngquist)

Leak Detection and Visualization Using Laser Shearography

There are currently over 12 techniques used to detect and locate leaks in the various fluid systems that are part of both ground and flight equipment in the Space Shuttle program. Often times, detection and location are carried out by completely separate methods that add both time and cost to the testing. A "full field" method for detecting, locating, and visualizing leaks was desired, and laser shearography has shown promise in this respect.

Laser shearography is an interferometric technique, meaning it is sensitive to constructive and destructive interference from phase differences in coherent light. "Shearing" optics are used to image multiple points of a laser-illuminated object onto a single picture element or pixel. In a real-time laser shearography system, like the one used in this investigation, the phase information at these points is collected by a video camera pixel array. At the beginning of a test, an initial video frame (called the reference frame) is captured and from which all subsequent live frames are subtracted. Differences, caused by phase changes, between the reference frame and the live frame are displayed in live shear images on a video monitor. Any change in the phase relation measured at an individual pixel, whether due to a path length change of some of the light initially imaged on that pixel or due to the bending of light causing more or fewer object points to be imaged onto that pixel, shows up in the live shear image as a variation in gray level. Laser shearography is, thereby, well suited to locate and measure very slight out-of-plane displacements or, as in this case, to locate substances that change the index of refraction in the object space.

Two captured images of leaks are shown in the figures. Figure 1 shows a very slight leak from an air duster can that is otherwise invisible to the naked eye. The air from the can, which is colder and denser than the ambient air, can be seen to be flowing downward in the image. Figure 2 shows a leak from a calibrated helium leak system of 2.8 x 10^{-3} c^3/s at 1 atmosphere. In this image, the helium (which is lighter than air) can be seen to be flowing upward.

What appears as two leaks in each of these images is actually a single leak and its "shadow." The laser illumination source was located approximately 1 inch above the camera, which explains the shadow of the leak fixture seen just below the actual leak fixture. The leak "shadow" was produced in a similar way. Light from the laser had two opportunities to pass through and be affected by the leak – once on its way from the laser source to the background (located approximately 3 inches away) and once on its way from the background to the camera. Since the laser was located above the camera, the upper indication is due to light passing through the leak after being reflected off the background. The lower indication is due to light passing through the leak before reaching the background. Where the two leak indications overlap is where light passed through the leak in both directions.

It was determined that helium leaks as small as 10^{-3} c^3/s at 1 atmosphere could be detected without additional image processing. Leaks were much more apparent in the live video as often the motion of the leak helped set it apart from background noise. Better results were obtained by capturing reference frames at short, regular intervals which helped eliminate the slow, constant increase in noise caused by slight changes in the surrounding environment. Future plans for leak detection with laser shearography include a probability of detection study of helium leaks in air and in a vacuum and studies of other types of leaks in several different environments.

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Participating Organizations: I-NET, Inc. (S.M. Gleman) and Dynacs Engineering Co., Inc. (J. Donahue, S.W. Thayer, and D.L. Thompson)

Figure 1. Air Duster Can Leak

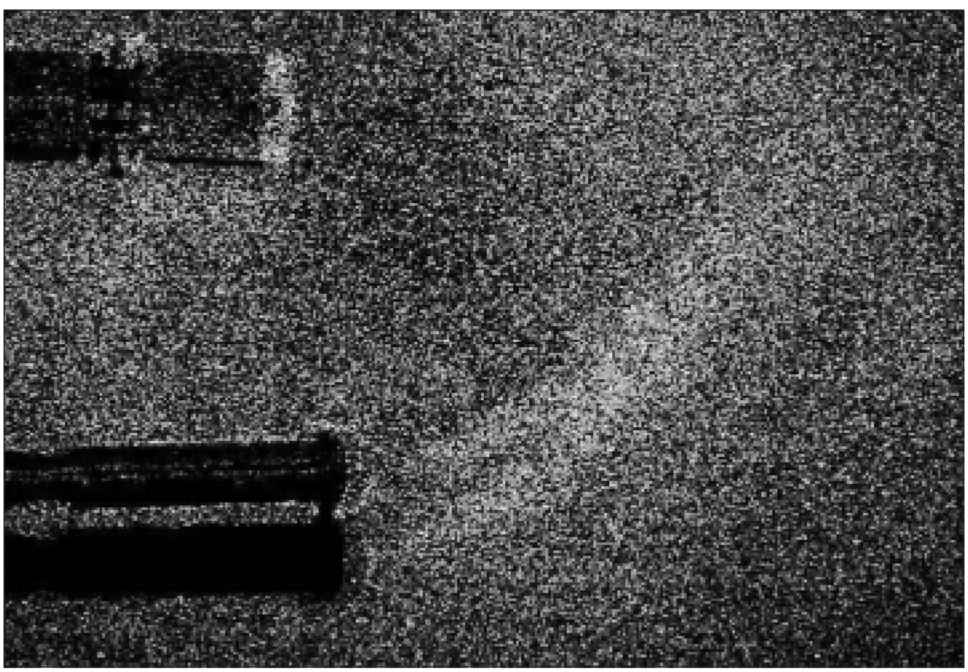

Figure 2. Helium Leak 2.8 x 10^{-3} c^3 at 1 Atmosphere

Support of the Linear Aerospike SR-71 Experiment (LASRE)

KSC has been launching vehicles for almost 40 years. The knowledge gained over this time has proven to be of use to other NASA centers and support contractors. One such area is that of checking vehicles for fuel leaks before launch. Recently, personnel from KSC were requested to assist Dryden Flight Research Center (DFRC) personnel in their effort to determine if the LASRE was safe for flight. Because the engine used gaseous hydrogen and liquid oxygen for the fuel and oxidizer, the experiment could not be flown until it was demonstrated to be free of leaks. KSC was contacted to assist DFRC because of difficulties arising while trying to leak check the engine.

The LASRE test plan included a small half-span model of the X-33 Aerospike Engine mounted onto an SR-71 aircraft. The engine was then to be flown to an altitude and test-fired. These experiments would answer questions about the performance of the engine as well as how a reusable launch vehicle's engine plume would affect the aerodynamics of its lifting body shape at specific altitudes and speeds. However, before the engine could be fired at altitude, it had to be shown to be free of fuel and oxidizer leaks.

In response to the request for support, KSC sent a mass-spectrometer-based system, namely the Interim-Hydrogen Umbilical Mass Spectrometer (I-HUMS), and personnel to DFRC to support the leak tests. I-HUMS was developed during the summer of 1990 to help find the leaks on the orbiters for flights STS-35 and STS-38. Helium and hydrogen were the only gas species monitored for these experiments, even though the I-HUMS can monitor additional gases. This report covers one of the two tests supported by KSC. This test was deemed the most valuable. Figure 1 shows the I-HUMS attached to the LASRE during a cold firing of the engine.

Figure 1. I-HUMS Under the SR-71 for Leak Checks

The leak test performed on the LASRE was based on the Shuttle Aft Helium Signature Leak Test (V1202), which is currently performed before each launch. The entire system was characterized because the LASRE had no history or baseline. The test required the I-HUMS to monitor helium at one sample location; the I-HUMS can support up to 16 sample locations. Because the purge was not a simple in/out model, it also was characterized. This is due to the fact that the feed system is distributed throughout the purged environment (see figure 2). Venting is through many tiny holes throughout the skin of the test article. Both of these characteristics made the purge path unknown.

The I-HUMS was used to monitor the purge of the LASRE while a calibrated helium leak rate was injected into multiple locations in the test article. The injection of a known leak rate into a known purge was used to characterize the engine purge. This characterization was subsequently used to determine the minimum signal that would be detected for a given engine leak. A second calibrated helium leak rate was injected to enable quantitation of any engine leak.

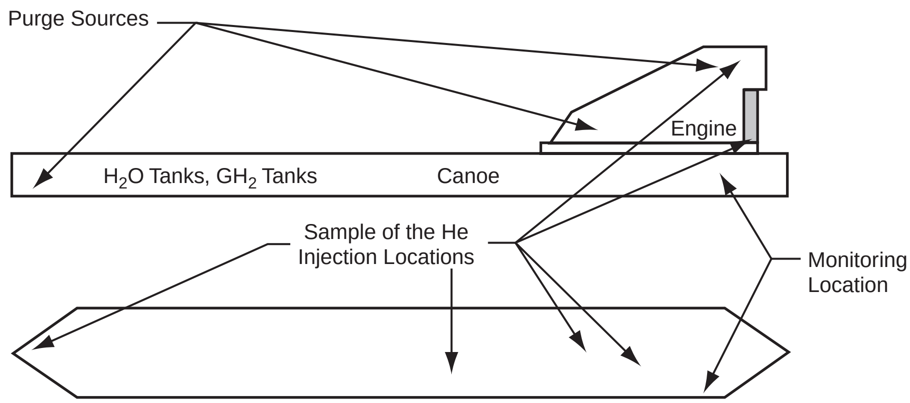

Figure 2. Layout of LASRE Leak Checking

After the engine purge was characterized, the engine was pressurized with helium. The I-HUMS was then used to monitor the helium levels in the purge until a level reading was reached. The helium pressure in the engine was then increased to a higher pressure. The helium levels in the purge were again monitored until a stable reading was reached. The recorded values were used to predict the operating leak rate. The planned operating time of the engine during altitude tests was extremely short, less than 15 seconds, so that only a fraction of the calculated leak rate would be introduced into the chamber during an actual flight.

These tests demonstrated that KSC has the knowledge and capabilities to help solve many problems at other centers. A further demonstration of the flexibility of the personnel and equipment at KSC is the fact that they will be used to support the X-33 launches.

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Participating Organizations: Dryden Flight Research Center (N. Hass) and Dynacs Engineering Co., Inc. (T.P. Griffin and G.R. Naylor)

Ferroelectric Camera for Infrared Fire Imaging

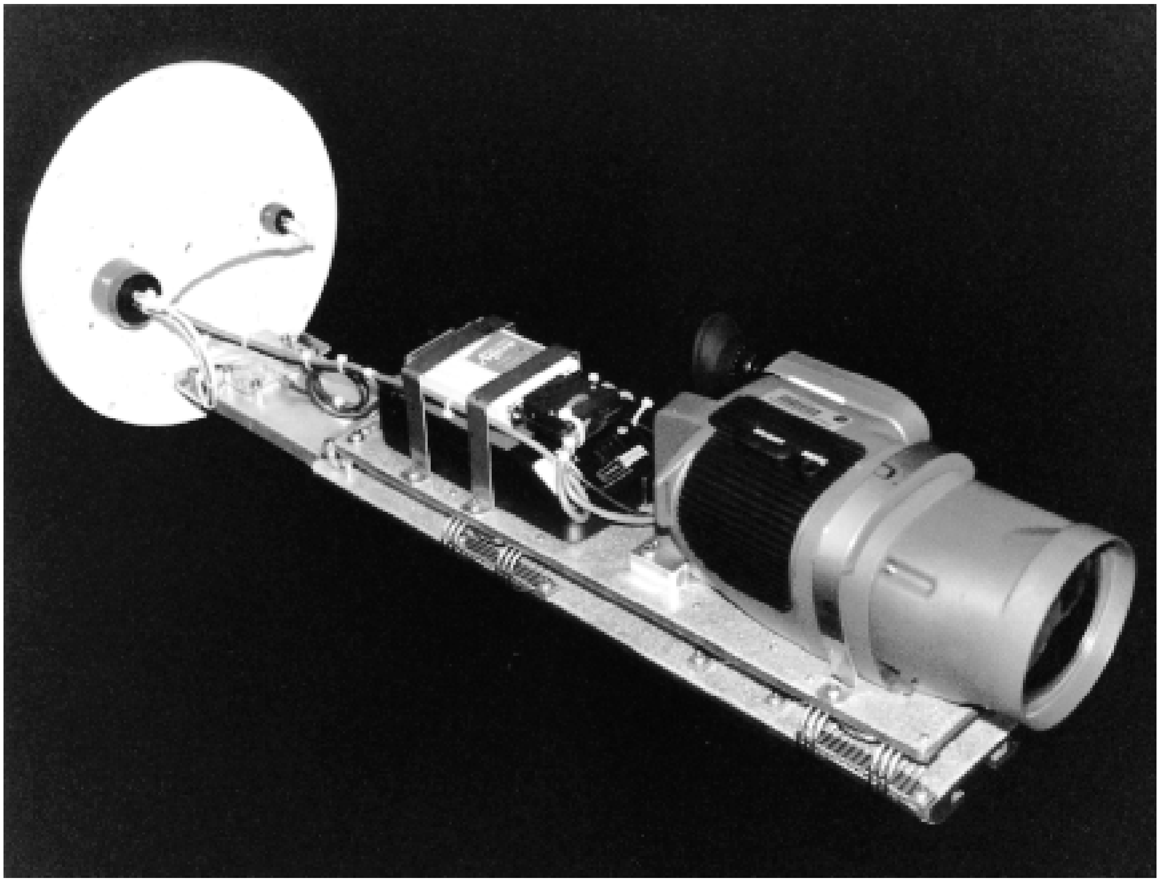
Infrared cameras are currently used at the launch pads to monitor hydrogen flow lines for fires. This is necessary because hydrogen fires, like natural gas fires, emit very little visible radiation and are virtually invisible under daylight conditions to the human eye or to normal silicon-based charge-coupled device (CCD) cameras. The currently used infrared cameras are deteriorating and the manufacturer, Insight Vision, has gone out of business, resulting in excessive maintenance costs and eventually, as spare parts run out, the loss of this capability. In order to deal with this problem, it was decided to replace the old infrared cameras with new, state-of-the-art cameras. A low-cost camera was located that appeared to provide adequate infrared images. This camera, a Palm IR 250 ferroelectric device, is popular as a nighttime people locator used by law enforcement groups and the Coast Guard. It is rugged, does not require cooling, and provides images in the 8- to 12-micron region of the spectrum. One of these cameras was purchased and configured for field operation at the launch pad with the goal to produce an image adequate to meet the monitoring needs of operations personnel.

Before purchasing the Palm IR 250 infrared camera, several versions were brought to KSC for field testing. They produced good images of the Shuttle on the pad from inside the perimeter fence and easily imaged hydrogen fire at the flame stack. A standard hydrogen fire (about a 1-foot-high flame) was set up at the fire training facility and was imaged from several distances against a variety of backgrounds. In all cases, the images of the fire stood out clearly and the performance was acceptable to operations personnel. One camera was aimed into the sun to see if the camera was damaged by a bright exposure such as it would see during a launch. The camera became saturated but recovered quickly with no apparent damage. Based on these successful demonstrations, a Raytheon TI Palm IR 250 infrared camera was procured for the Optical Instrumentation Laboratory to use during the STS-91 external tank (ET) tanking test and launch (May 1998).

In summary, the camera was strapped down to a plate with a power supply and microcontroller strapped down behind it. This plate sits on a set of six vibration isolators attached to a slide rail assembly welded to the backplate (see the photo). Standard operational television (OTV) connectors were placed on the backplate with the pan-and-tilt signals fed through the camera housing to a pan-and-tilt connector. A germanium window was mounted in the frontplate, allowing the camera to look out of the housing in the 8- to 12-micron region. A Blue Earth Research microcontroller was programmed to allow the OTV analog voltage levels to be converted into RS-232 commands to control the camera. Gain, level, auto / manual switching, and focus were provided as operator-controllable features through this communication system. Significant effort went into ensuring the housing was well sealed so it could be pressurized to a few pounds per square inch in the field and would hold this pressure for a period of days.

United Space Alliance tested and verified the performance of the completely housed and configured camera system, and the system was installed on Launch Pad 39A. The video signal was sent through the Launch Control Complex OTV routing system.

Initially, the camera was aimed at a variety of objects around the pad and produced good infrared images; however in the cool early morning hours, the camera showed a dark image with minimal imaging. This was explained as a limitation in the sensitivity of the camera. Earlier testing had not disclosed this because the testing was done during warm daytime conditions. During a cool night when the ambient temperature dropped, the camera had trouble seeing background objects and produced a dark image. This condition would make it difficult to locate the position of a fire if background objects could not be seen. It was decided, however, that the Palm IR camera would be left in the field for the ET tanking test and the launch.



The camera performed well during the tests. It produced good infrared images of the orbiter before and during launch and was able to remain running even during launch. This was important because the existing Insight Vision cameras must be shuttered during actual launch, which prevented monitoring the area for fires during a short but critical period. The Palm IR camera actually spotted a fire after the launch; a patch of dried grass near the pad had caught fire during launch. Shortly after launch, the camera was brought back to the Optical Instrumentation Laboratory, and the decision was made that a better (i.e., lower detection temperature) camera was required for fire imaging at the launch pad. Work is ongoing to choose such a camera and to procure one or more for field trials during 1999.

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Participating Organizations: United Space Alliance (D. Carter and D. Exley), MM-J1-A (L. Hand), PK-G (K. Brock), and Dynacs Engineering Co., Inc. (R.B. Cox, W.D. Haskell, F. Lorenzo-Luaces, and R.C. Youngquist)

6U VME Universal Signal Conditioning Amplifier (USCA) Interface Module

The objective of this project is to develop a 6U VME bus card and software to interface with the USCA's. The combination of the 6U VME module and the hardware will allow users to develop customized data acquisition solutions using USCA's and commercial off-the-shelf 6U VME hardware.

The module will receive serial data streams from the USCA's, will decode and buffer the data, and will transport the data over a VME bus for data archival and transmission. The module will also be used to communicate commands to and receive status information from USCA's in the field.

Key accomplishments:

- A low-speed prototype was designed and built.
- The development of a VXWorks driver for the card was started.

Key milestone:

- Complete the development of the 6U VME interface module and supporting hardware.

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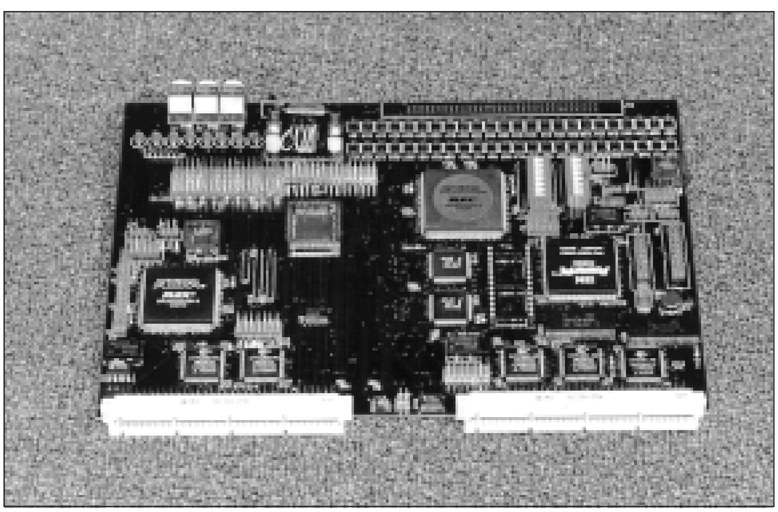
Participating Organization: Dynacs Engineering Co., Inc. (P.J. Medelius and J.J. Henderson)



Medical Aeronautical Communications System

KSC relies upon Department of Defense helicopters to support search, rescue, and medevac for flight crew and personnel supporting Shuttle program launches and landings. These helicopters are normally configured for military combat missions and must be reconfigured rapidly to support the NASA mission on launch and landing days. Communications are necessary with KSC medical, fire, safety, and rescue radio nets as well as hospital emergency rooms throughout the state. However, military communications systems aboard these helicopters are not compatible.

The Biomedical Laboratory has designed, fabricated, and put into place a Medical Aeronautical Communications System that provides (1) VHF-FM / simplex radio communications capability on all KSC radio nets; (2) UHF-FM / duplex communications to hospitals, the Launch Control Center (LCC) firing room, and the clinic; and (3) a seven-station private / helicopter intercom system. This allows the physician aboard the helicopter to talk with the two assigned pararescuemen as well as the two patients. The flight engineer also has access to the system, and a spare access is provided. The system has been programmed to permit communications on U.S. Coast Guard frequencies for those helicopters providing Range Safety clearing of shipping assets in the solid rocket booster drop zones at sea.

This system is battery operated and interfaces the helicopter intercom system with impedance that makes it appear as a single headset. A unique external antenna system is provided that exchanges the standard hoist hook access door with a similar functioning structure which exposes VHF and UHF antennas out of the bottom fuselage of the airframe. Testing and mission usage thus far aboard four HH-60G Blackhawk helicopters have shown the system to be a significant improvement over the previously disclosed portable system carried aboard these helicopters.

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Portable Magnetic Field Sensor for Measuring Lightning Effects

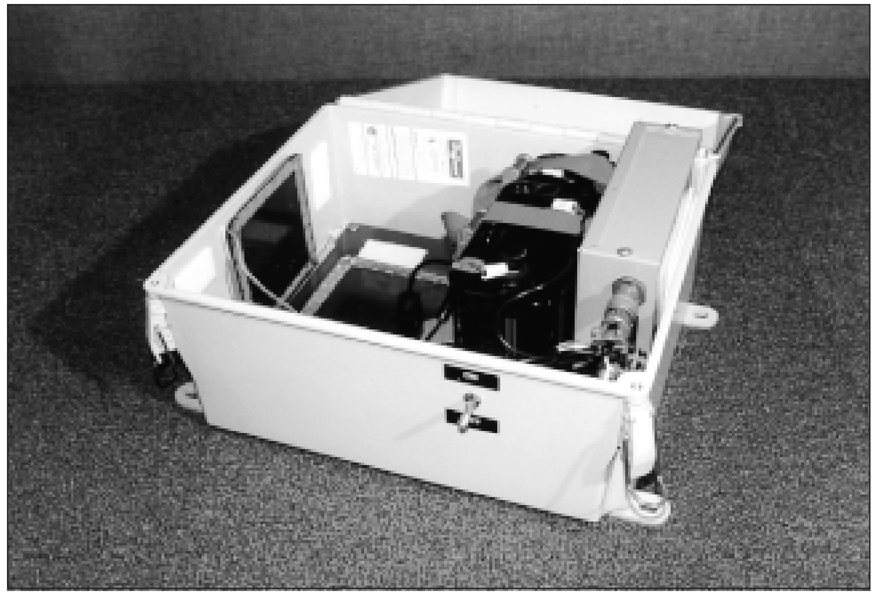
The objective of this project was to design a reliable sensor for measuring magnetic fields inside the Payload Changeout Room (PCR) on each launch pad. Information obtained by the sensor will be used to determine the magnitude of the voltages induced into cables by the magnetic field generated by a lightning strike. Depending on the distance to the lightning strike and the area covered by the conductors, the induced voltage can reach several thousand volts for a duration of close to 100 microseconds.

A complete magnetic field measurement requires the use of three orthogonally placed antennas. This requires the use of three data conditioning, digitization, and storage channels. It is important to keep the total power consumption to a minimum in order to extend the lifetime of the batteries in the sensor.

The sensor was designed with three data conditioning and digitization channels, with only the first channel continuously powered up. Under normal operating conditions, data from the three orthogonal antennas is sampled sequentially at a 1 mega sample per second (MS/s) rate. Upon detection of a nearby lightning strike, the following actions take place:

1. The data from the preceding 100 microseconds is stored.
2. The power to digitization channels 2 and 3 is restored.
3. The multiplexer stops alternating among the three channels and connects each antenna to each digitization channel.
4. The clock signal for all three digitizers is set to 30 megahertz.
5. Data is acquired for an additional 100 microseconds at a 30-MS/s rate.
6. The power to channels 2 and 3 is removed.

The data preceding the trigger is sampled at 1 MS/s, and the data following the trigger is sampled at 30 MS/s. The latency between the onset of the trigger and the sampling clock switch is in the order of a fraction of a microsecond. This operation results in most of the information being sampled at the fast rate, thus preserving the data integrity. Since the sensor is never put into a “sleep” mode, even magnetic fields from a first lightning strike can be acquired. A significant reduction in power consumption is achieved by powering up only one digitizing channel and multiplexing all three measurements through that channel and digitizing the measurements at a reduced sampling rate.



Key accomplishment:

- The circuit schematic design was completed.

Key milestone:

- Continue monitoring induced magnetic fields inside the PCR.

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Participating Organization: Dynacs Engineering Co., Inc. (P.J. Medelius)

Inline Gas Analyzer for Cryogenic Hydrogen

A prototype inline gas analyzer (IGA) for cryogenic hydrogen was designed, constructed, tested, and temporarily installed at the hydrogen flare stack on Launch Pad 39B. NASA's intent is to use the IGA system to reduce the man-hour requirements and material costs of vehicle preparations for cryogenic fuel loading and safing during and after Space Shuttle launch operations. With the IGA system, measurements of the cryogenic operations can be monitored from a remote, safe location during hazardous operations. The current method for doing these measurements is to take a melon sample for each test point and analyze it in the laboratory using a mass spectrometer and manual field verification of gas concentrations. If the prototype program is successful, the final design will be permanently installed at the hydrogen flare stack, the Mobile Launcher Platform (MLP) liquid hydrogen (LH_2) high point bleed (back porch), and the Fixed Service Structure (FSS) gaseous hydrogen (GH_2) vent line at Launch Pads 39A and 39B at KSC. The IGA contains hydrogen, oxygen, and water sensors to monitor critical concentrations of each of these materials. The flow path of the sample gas is from the hydrogen cryogenic line through the IGA and back to the cryogenic line (see figure 1). In addition to the concentration data for hydrogen, oxygen, and water, the system provides calibration parameters, the ability to recalibrate the sensors, flow rates through sensors, the temperature and pressure of the sample gas, and error data for essential components. The following are general characteristics of the IGA:

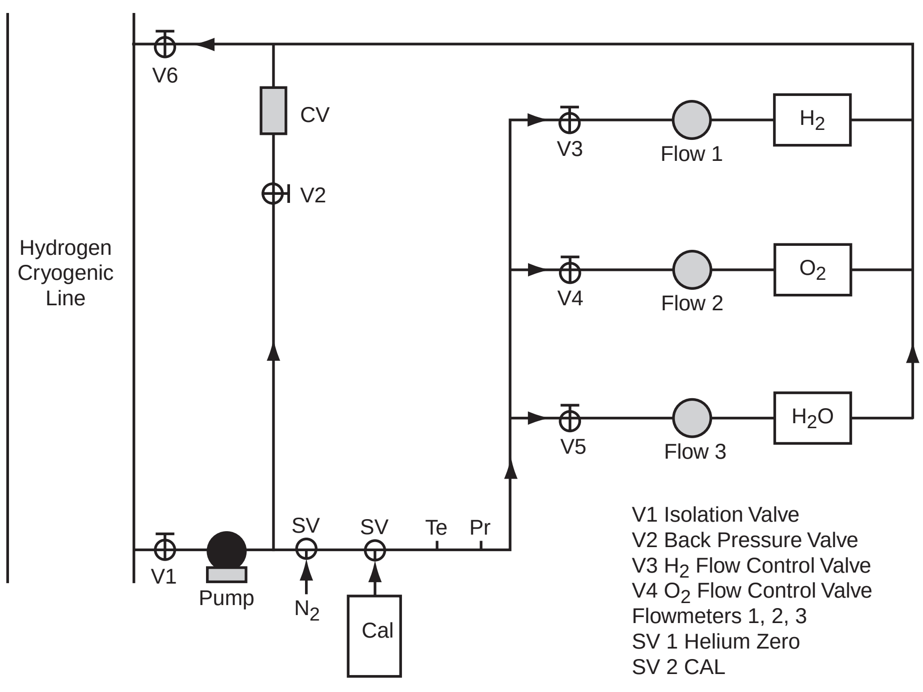

Figure 1. Inline Gas Analyzer

1. The hydrogen sensor can measure the concentration of hydrogen at ±1 percent full scale over the range of 0 to 10 percent. It can operate over the temperate range from -10 to 60 degrees Celsius (°C) and can withstand the sound and vibration conditions of a Shuttle launch.

2. The oxygen sensor can measure the concentration of oxygen at ±1 percent full scale and has a range of 0 to 2 percent. It can operate over the temperature range from -10 to 40 °C and be able to withstand the sound and vibration conditions of a Shuttle launch.

3. The humidity sensor can measure the concentration of water at 125 ±10 parts per million (ppm) and has a range from 125 ppm to 4 percent. It can operate over the temperature range from -10 to 40 °C and withstand the sound and vibration conditions of a Shuttle launch.

A microcomputer acquires the data from the sensors and formats the data in a manner suitable for transmission over a serial data line. In addition, provisions are made to allow for control of solenoid valves from a remote terminal via the serial data line or locally from the microcomputer using pushbuttons. The microcomputer provides 12-bit analog

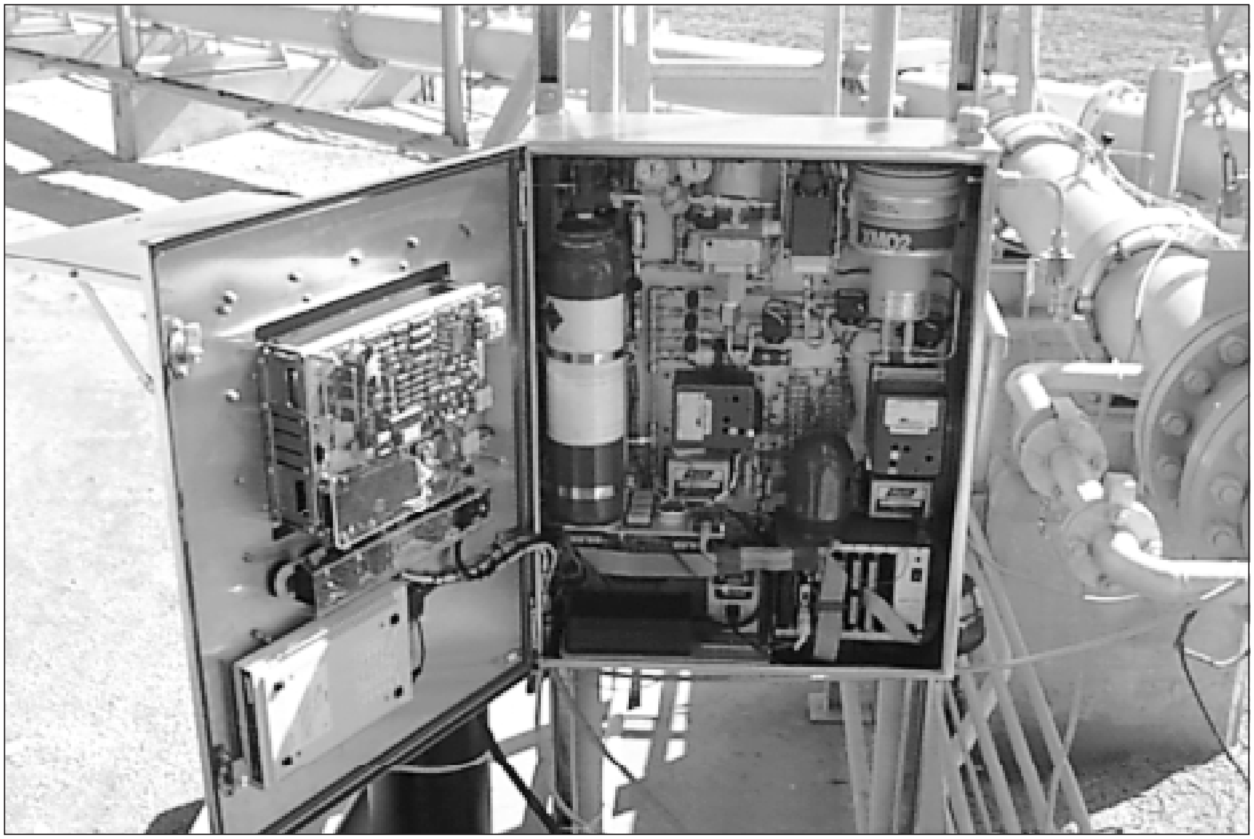

Figure 2. Inline Gas Analyzer With the Moisture, Hydrogen, and Oxygen Analyzer

inputs, digital inputs, and digital outputs capable of driving the solenoid valves. The software allows the sensor data to be formatted and the controls and valve talkbacks to be processed and displays the results. The software also provides control via the serial port, which mimics the functions of the buttons and provides diagnostic functions. Figure 2 shows the installation of the inline gas sensor at the hydrogen flare stack at Launch Pad 39B.

Key accomplishments:

- A prototype IGA was designed, constructed, tested, and temporarily installed at the hydrogen flare stack at Launch Pad 39B.
- The IGA was successfully used to monitor a storage tank loading operation and found transients in moisture and oxygen previously unknown.

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Participating Organization: Dynacs Engineering Co., Inc. (C.F. Parrish, C.J. Schwindt, S.J. Klinko, and T.R. Hodge)

Space Shuttle Orbiter to External Tank Mating Tool

During Space Shuttle processing, the orbiter is joined to the external tank (ET) in a process called mating. This takes place with both the orbiter and ET in the vertical position. Two mating fixtures, located at the aft end of the orbiter and ET, are used in the mating process. These fixtures are composed of ball-and-socket-type joints with the ball ends on the ET side and the socket receptacles on the orbiter side (see figure 1). During mating, the orbiter is suspended by crane and slowly brought into contact with the fixed ET. Once the two are in contact, bolts are attached through the ball-and-socket joint to secure the orbiter to the ET.

The mating operation is currently accomplished using caliper and eye-ball measurements in an iterative approach, which carefully brings the orbiter into contact with the ET. The orbiter is initially positioned at approximately the correct height and then slowly moved towards the ET. As the orbiter gets closer, measurements are made to determine if the two mating surfaces are aligned. If they seem to be aligned, the orbiter is moved slightly closer to the ET and more measurements are taken. If they are not aligned, the orbiter is repositioned slightly and then rechecked. This process of checking for alignment, repositioning, and moving closer is repeated until the orbiter and ET mating surfaces are brought into contact and the two are secured. Due to the critical nature of this task, a more precise guiding technique was desired. A laser-based targeting system was created that can be used to align the mating components with more precision and ease than currently possible.

The laser targeting system is composed of a laser mount that goes on the ET side and a target that goes inside the orbiter. Two systems are required for each mate, one for each side of the ET and orbiter. The targets, which are made of a type of plastic, fit over the screws used to secure the attachment nut inside the orbiter. This nut is used to capture the bolt for connection to the ET. The targets are positioned to be perfectly centered with respect to this bolt.

The laser mounts (see figure 2) attach to the back side of the bolt clearance holes in the ET fixtures. The mounts are designed to fit snugly within the

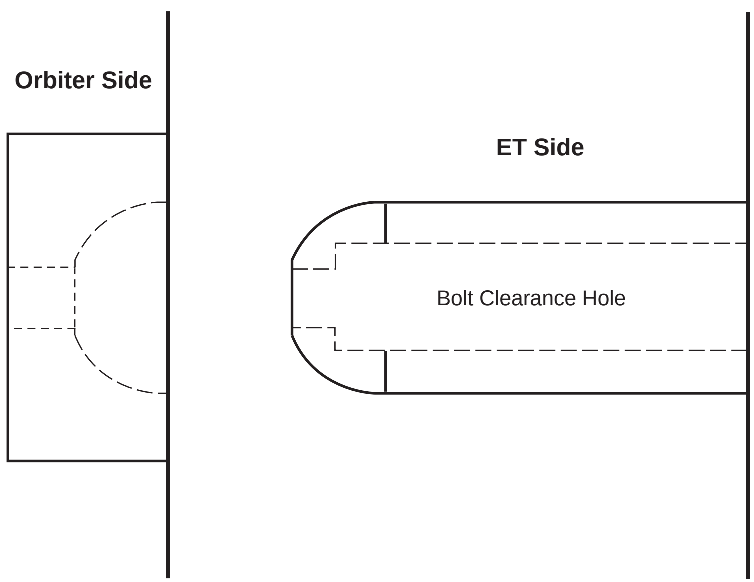

Figure 1. Mating Fixtures

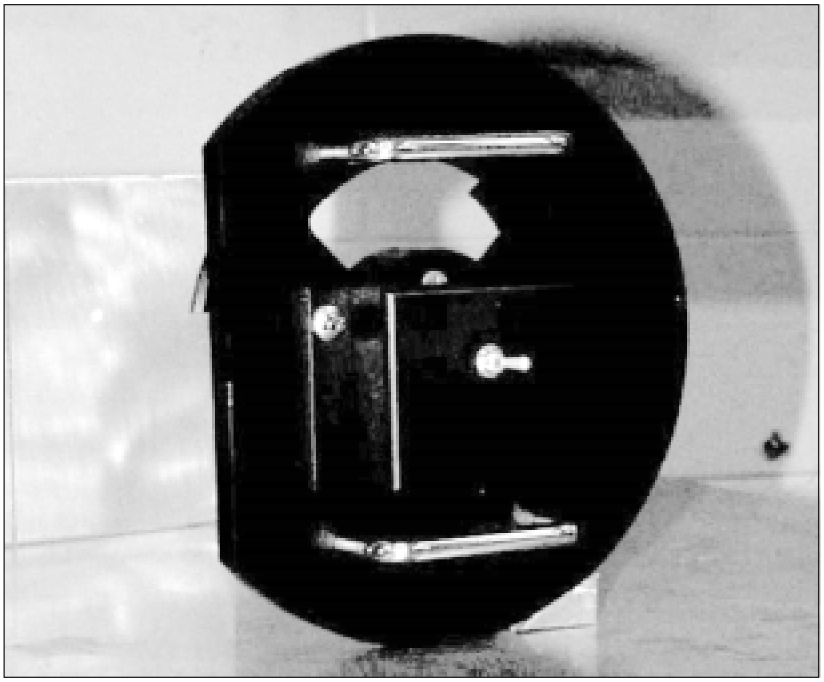

Figure 2. Laser Mount

clearance holes to provide the necessary concentricity for the laser. The laser is positioned within the mount to shine down the center of the clearance hole and directly through the center of the bolt hole. When the orbiter is within range, a window cut into the mount allows the user to look directly down the bolt hole and into the aft compartment to see where the laser spot falls on the target. The target is equipped with a graded scale so the user can tell exactly, to within 1/16 inch, how far out of alignment the orbiter is at any given time. Two sets are used to help ensure both sides of the orbiter are at the correct height necessary for mating.

This system has already undergone preliminary testing during the mating operation of STS-88. Targets were not able to be installed, but the laser mount was tested for fit and functionality. The laser mount was found to fit extremely well within the ET fixture and the laser spot could be easily seen on the protective backing placed behind the attachment nut inside the orbiter. Also, using the inner diameter of the nut as a reference, the laser spot was used to roughly determine the position of the orbiter. The position determined in this fashion corresponded well to the position determined using the current procedure. A full test of the system is planned for the mating operation of Columbia mission STS-93.

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Main Three Contamination Monitoring Cart

The Contamination Monitoring Laboratory at KSC developed a system that provides three types of real-time molecular contamination monitoring in one system for support of highly sensitive payload processing. It incorporates an airborne hydrocarbon monitoring system based on Fourier Transform Infrared (FTIR) technology, real-time optical fallout monitors to monitor particulate fallout, and Surface Acoustic Wave (SAW) nonvolatile residue (NVR) monitors for sensing molecular contamination. The system consists of a portable cart suitable for use in class 1, division 2, environments (see the figure) that is electromagnetic interference (EMI) shielded.

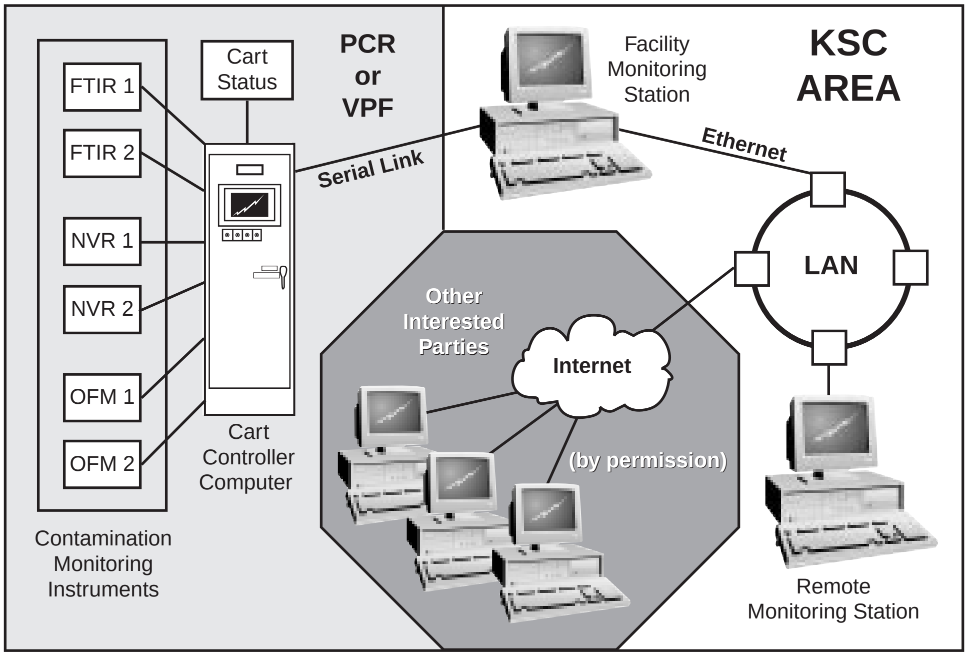
The capability to monitor contaminants is essential in order to protect sensitive optical payloads from performance degradation caused by the deposition of surface films, other molecular contamination, and particulate fallout. Commonly used hydrocarbon monitoring instrumentation, such as flame ionization detectors, yields no information about the source or identity of the compounds they detect. The FTIR technology with its inherent ability to discriminate a large number of compounds offers a tremendous advantage over other types of instrumentation. Recent developments in the areas of real-time detection of particulate fallout and nonvolatile residues have, for the first time, allowed creation of an integrated instrument to provide fairly complete monitoring of the contamination risk to a payload during ground processing.

The hydrocarbon monitoring subsystem consists of two modified MIDAC FTIR instruments mounted in a cart; a computer providing control, user interface, and communications; and a sampling system. The graphical user interface runs on the cart controller computer, which has a keyboard, mouse, and monitor. The hydrocarbon portion of the cart is capable of measuring a variety of compounds and can be reconfigured to accommodate new compounds of interest. The MIDAC instruments were modified by the addition of a small computer inside the instrument case that controls the operation of the FTIR and provides deconvolution of spectral data. Each FTIR module sends gas concentration data to the cart controller computer, is equipped with a 1.8-meter gas cell, and runs at a resolution of 4 wavenumbers. The sampling system consists of two eductor pumps supplied by the system purge gas. There are also flow failure indicators that are monitored by the cart controller computer. The FTIR module makes use of a classical least square (CLS) algorithm in the analysis of spectral data. The traditional CLS method has been modified by the use of baseline correction algorithms, which correct errors due to instrument warmup, aging of the source, and degradation of the optics due to contamination. This correction is accomplished by performing a parametric shape fit for the baseline using three parameters: bend, tilt, and offset.

The NVR's are monitored with a Femtometrics SAW device that consists of a control unit inside the purged cart and a sensor head with an exposed quartz crystal to collect the residue. The increase in mass due to the residue deposition causes a shift in the resonant frequency of the crystal, which then can be used to quantify the residue mass. The SAW is extremely sensitive, roughly 100 times the sensitivity of a Quartz Crystal Microbalance. A 50-hertz shift in the frequency of the SAW crystal corresponds to only 1 nanogram per square centimeter mass density.

Particulate fallout measurements are made by optical fallout monitors (OFM's) that were developed at KSC. These instruments measure the light scattered from a specular surface by the particles which land on that surface. This instrument is calibrated to read out in "percent area coverage," which is the total fractional area of the witness plate obscured by particles.

The data from the two FTIR modules, the two SAW devices, and the two OFM's are integrated into a single software package that runs on the cart controller computer. Here, the data are logged in a disk file and presented to the user in several



Contamination Monitoring Cart Data Flow

forms, including tabular and graphical. The user can opt to view any or all the cart measurements. The cart controller software was written in Microsoft Visual Basic. All the data from the cart is put into a single data stream and sent via a serial link to a remote computer that can be located in another building. Here, the data is presented in the same way as on the cart controller computer, so the user at the remote site sees exactly the same data in real time. This remote system also is configured as a user datagram protocol (UDP) server and, if connected to a local area network that supports the Internet Protocol, can broadcast the cart data in real time to many remote users simultaneously anywhere in the world. These remote users can see the same screens as the local users but can select their own options for which data to view. The server can be configured to only allow certain domains to access the information so the availability of the data can be restricted to only those who are authorized to see it. This is the same technology that is used for “Internet broadcasts” of video and audio. To view the data from anywhere in the world, all that is required is the UDP client software (also written in Visual Basic) and a personal computer compatible with an Internet connection and authorization on the UDP server to allow the user to connect.

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Thermographic Inspection of Subsurface Voids in Composite Structures

Composite structures are becoming more prevalent at KSC and in many high technology industries. The ability to nondestructively evaluate composite structures to detect and locate surface and subsurface defects is, therefore, becoming increasingly important. Infrared (IR) thermography can be extremely useful in this type of nondestructive evaluation (NDE).

Large temperature differences in very hot objects can be seen as changes in color, as in the color of a flame or a star. In the same way, slight temperature variations, at or about room temperature, can be seen as changes in the IR range of the electromagnetic spectrum (wavelengths usually in the 1- to 20-micron range). In thermography, detectors sensitive to IR wavelengths are used to examine the thermal behavior of test objects. As an object's temperature changes, the amount of energy it emits in the detector range also changes. Using an array of detectors, an IR camera converts these differing energy outputs to video images of differing colors or gray scales.

Many objects change temperature inherently over time and can be easily studied by monitoring their behavior with an IR camera. For objects that do not inherently change temperature, heat excitation can be used so the behavior of the object during cooling can be examined. Flashlamps were used as the heating source in all experiments conducted for this report. Flashlamps emit a short burst of mainly visible and IR radiation, part of which is reflected at the object's surface; a large part is absorbed. The absorbed radiation is turned into heat at the object's surface, which increases its temperature. After the flash, the surface temperature slowly returns to ambient as the extra heat dissipates deeper into the test object and out into the surrounding environment. The amount of excitation energy initially absorbed and the rate at which the surface returns to ambient temperature can both be used to detect anomalies on the surface of and within the test object.

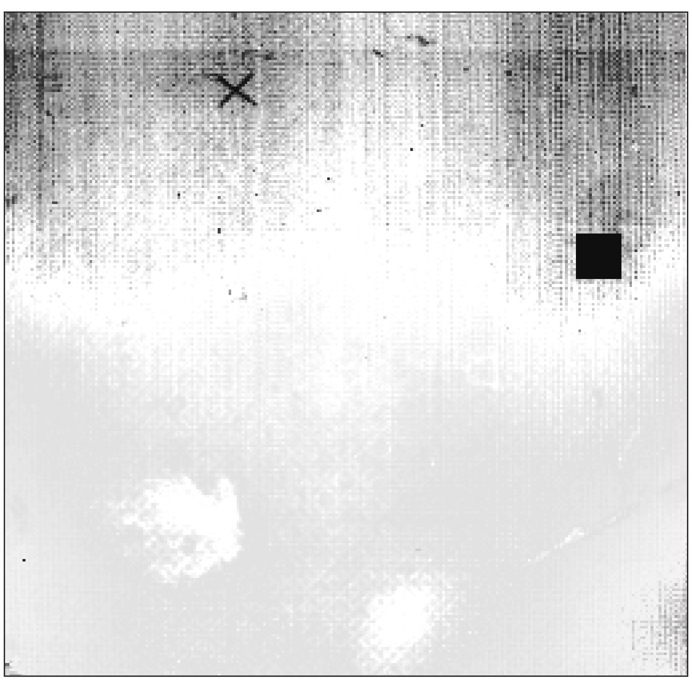

Figure 1. Surface Variations

Immediately after the excitation pulse (the flash), hotter or cooler areas show where more or less energy was initially absorbed by the object. Figure 1 shows an object with a temperature gradient from top to bottom as well as a small "X" and a square (top left and right center, respectively) which were scratches in the surface and several "hot spots" (lower left and center). These were all caused by differences in a reflective surface coating on the test object. Places that appear darker in the image are actually hotter and represent areas that were not as completely covered by the reflective coating.

As the object cools, anomalies within the test object can be detected through variations in the rate of surface cooling. The

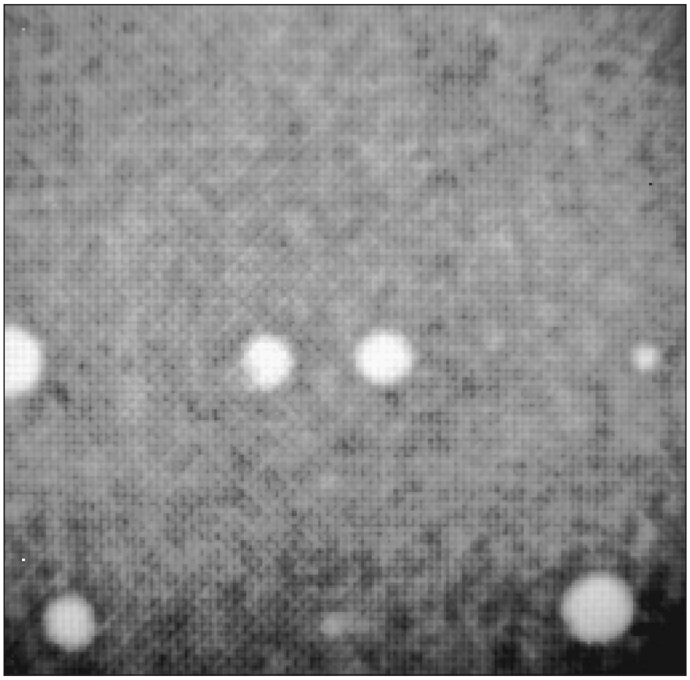

Figure 2. Subsurface Defects

dissipation of heat from the surface happens through three different routes: (1) from the surface into the surrounding environment, (2) from hotter areas on the surface laterally to cooler ones, and (3) from the surface into and through the test object. Given the proper environmental and initial conditions, heat loss through the first two routes will be fairly constant across the object's surface. In that case, areas that exhibit anomalous cooling must be due to variations in heat flow through the test object.

The rate of heat flow through the test object is dependent upon the path the heat must travel. The presence of good heat conductors or good insulators along this path will affect how quickly the heat is able to leave the surface and how quickly the surface can cool. For example, in these experiments, the presence of voids (air pockets) in the interior of the composite structure was of specific interest. Air is a better insulator than the materials that make up the composite structure so heat flow is slower along a path with an air pocket. This results in the surface above the air pocket remaining at a higher temperature than the surrounding surface for a longer time. Hot spots that were not immediately visible which appear during cooling could indicate possible voids within the structure. Figure 2 shows several indications of voids in a preprogrammed test panel. Both the size and shape of the voids are clearly visible. The rightmost and bottom-center defects are both 1/4 inch in diameter and the total field of view is approximately 6 by 8 inches. The resolution of thermography is one reason it has proven so effective in this type of evaluation.

Thermography is a fairly old field, yet improvements are happening at an incredible rate. The ability of thermography to work so well with composite materials coupled with the dramatic increase in IR detector capabilities suggests that thermography will play a more important role in NDE in the immediate future.

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Automatic Calibration Station for the Universal Signal Conditioning Amplifier (USCA)

The goal of this project is to design an automatic calibration station for the USCA. The USCA is a self-configuring amplifier designed to interface with a variety of transducers. Parameters such as gain, excitation voltage, sampling rate, and filtering are automatically set based on information stored in a small memory device attached to the transducer. The data on the Transducer Electronic Data Sheet (TEDS) is read by the USCA immediately after the connection to the transducer is detected. Calibration factors stored in the USCA's memory are used to ensure the accuracy of measurements is maintained within specifications.

Following the manufacturing process, the USCA has to be fully calibrated before deployment in the field. The calibration has to be repeated periodically (every 1 or 2 years). The calibration procedure also has to be repeated following any repairs that involve components associated with the analog circuitry. The calibration process includes measuring the reference voltages that the USCA uses for its self-calibration, measuring the precision resistors used for current measurements and current excitation, correcting for offsets, and others. The manual process takes about 30 minutes to complete when conducted by an experienced technician.

The USCA requires certain parameters to be stored in its nonvolatile memory in order to perform its continuous self-calibration. These parameters include three reference voltages, zero offsets, current sensing resistor values, excitation resistor divider ratios, and input voltage resistor divider ratios. A combination of custom-developed software in the USCA and a LabView-based program running on a personal computer is used in conjunction with an external voltage / current source to fully automate the calibration process. The automated calibration process performs additional detailed tests that are not normally conducted during manual calibration and is expected to take about 15 minutes to completely calibrate a USCA.

Key accomplishments:

- Started the design of the Automated Calibration Station.
- Developed a method to fully calibrate a USCA without the need to remove it from its sealed enclosure.

Key milestone:

- Evaluate the performance of the system and refine the software if needed.

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